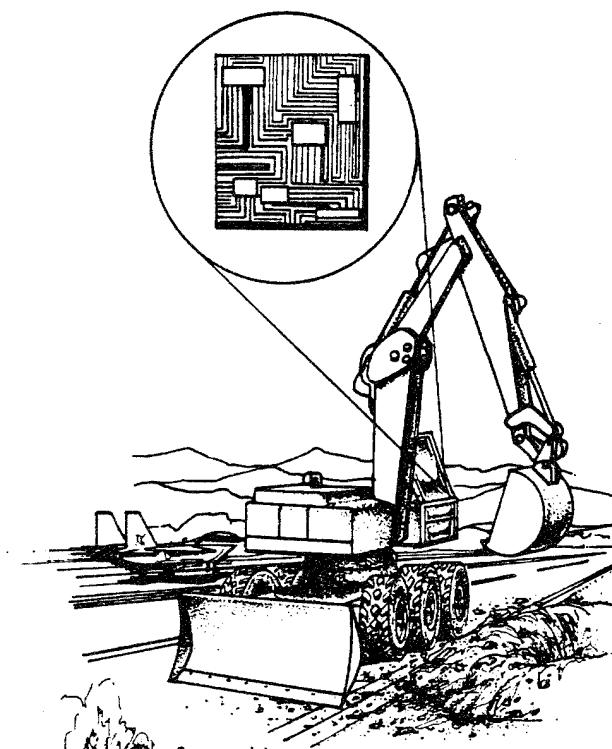


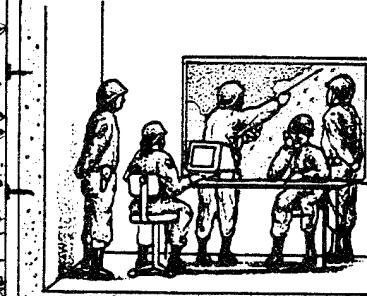
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IMPACT TO USAF FROM NATIONAL  
AND INTERNATIONAL RESTRI-  
TIONS ON USE OF OZONE-DEPLETING  
SUBSTANCE

T.D. McCarson, Jr., Robert E. Tapscott

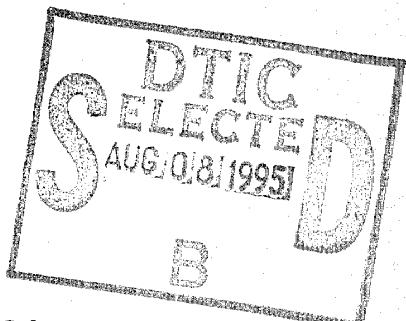
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APRIL 1995



FINAL REPORT



MAY 1990 - APRIL 1991

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1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE April 1995	3. REPORT TYPE AND DATES COVERED Final Report, May 1990 - April 1991	
4. TITLE AND SUBTITLE  <b>IMPACT TO USAF FROM NATIONAL AND INTERNATIONAL RESTRICTIONS ON USE OF OZONE-DEPLETING SUBSTANCES</b>		5. FUNDING NUMBERS F29601-C-87-0001	
6. AUTHOR(S)  T. D. McCarson, Jr., and Robert E. Tapscott			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)  New Mexico Engineering Research Institute University of New Mexico Albuquerque, New Mexico 87131-1376		8. PERFORMING ORGANIZATION REPORT NUMBER SS 2.16(3)	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)  Air Force Civil Engineering Laboratory Air Force Civil Engineering Support Agency Tyndall Air Force Base, Florida 32403-6001		10. SPONSORING/MONITORING AGENCY REPORT NUMBER ESL-TR-91-36	
11. SUPPLEMENTARY NOTES			
12a. DISTRIBUTION/AVAILABILITY STATEMENT		12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words)  The objective of this project was to assess the impact on the U.S. Air Force (USAF) of national and international restrictions on the production and use of chlorofluorocarbons (CFCs), halons, and other substances believed to contribute to stratospheric ozone depletion. The Montreal Protocol (a United Nations agreement) and the U.S. Clean Air Act Amendments of 1990 place restrictions on the production and use of CFCs and halons with eventual phaseout of production by the year 2000. CFCs are widely used as refrigerants, cleaning solvents, sterilants, foam-blowing agents, and aerosol propellants. Halons are used primarily as fire and explosion suppression agents.			
14. SUBJECT TERMS  chlorofluorocarbons; halons; Montreal Protocol; ozone depletion; Clean Air Act Amendments of 1990; halocarbons			15. NUMBER OF PAGES
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT  UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE  Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT  Unclassified	20. LIMITATION OF ABSTRACT  Unclassified

NSN 7540-280-5500

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## **EXECUTIVE SUMMARY**

### **A. OBJECTIVE**

The overall objective of this project was to assess the impact on the United States Air Force (USAF) of national and international restrictions on the production and consumption of chlorofluorocarbons (CFCs), halons, and other substances believed to contribute to stratospheric ozone depletion.

### **B. BACKGROUND**

Scientific evidence is continuing to increase that manmade substances released into the atmosphere are depleting ozone levels in the stratosphere. Growing worldwide concern over stratospheric ozone depletion has led to an international agreement (Montreal Protocol) to phase out chlorofluorocarbon and halon consumption (defined as production minus exports plus imports) by the year 2000. Chlorofluorocarbons are widely used as refrigerants (in mobile air-conditioners, stationary refrigeration and air-conditioning units), cleaning solvents, sterilants, foam-blown agents, and aerosol propellants. Halons are used primarily as effective and clean-fire and explosion-suppression agents. The phaseout of these compounds will significantly impact both industrialized nations and emerging nations. A massive effort, already underway, is required to find alternative compounds, equipment, and processes to replace CFCs and halons by the year 2000.

### **C. SCOPE**

This assessment includes substances regulated by the Montreal Protocol, as well as all other substances suspected of being stratospheric ozone depleters in use now or planned for use in the future by the USAF. An in-depth technology assessment was conducted to identify alternative compounds, availability dates, whether they are "drop-

in" replacements or require new hardware/systems, and, when possible, projected cost impacts to the USAF. The inventory and end-use data were used to assess the impact of the phaseout schedule of CFCs and halons on USAF operations, with emphasis on critical-use categories.

#### D. METHODOLOGY

Extensive literature reviews and attendance at state-of-the-art CFC and halon replacement conferences were used to make an up-to-date technology assessment on replacements and alternative strategies. The report to Congress on the "DoD Program to Reduce the Unnecessary Release of Chlorofluorocarbons and Halons into the Atmosphere," (1990) was used as the primary data source for USAF consumption and broad end-use identification of CFCs and halons.

#### E. TEST DESCRIPTION

This was a technology and impact assessment study and did not involve testing.

#### F. RESULTS

The state of current technologies for replacement of CFCs and halons used in refrigeration, solvent cleaning, foam blowing, fire and explosion suppression, and some miscellaneous use categories is clearly identified. The impact of the phaseout of CFCs and halons on USAF operations and overall mission is assessed.

#### G. CONCLUSIONS

A broad-based USAF program with commitment of significant resources is required to make a successful transition from CFC and halon uses. Many uses of CFCs and halons within the USAF are similar to uses in the private sector. Technologies for

replacements in the private sector are progressing well to meet the phaseout schedules in the areas of refrigerants, solvents, and foam blowing. Halon replacement technologies are moving more slowly than those for CFC replacement. Many applications will require stored banks of CFCs and halons to meet future mission-critical uses while replacement chemicals or alternative methods are found or developed.

#### H. RECOMMENDATIONS

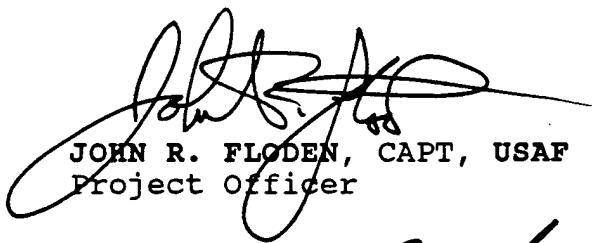
A major commitment of resources at all levels of the USAF is required to meet the required reductions in CFC and halon use by 2000. There is an immediate need to begin a conservation, recovery, and recycling program to minimize emissions and conserve CFC and halon resources for critical future needs. Research programs are needed to find halon replacements, particularly for mission-critical applications. A "bank" of CFCs and halons needs to be established and managed to meet mission-critical needs until replacement agents are available.

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PREFACE

This report was prepared by the New Mexico Engineering Research Institute (NMERI), The University of New Mexico, Albuquerque, New Mexico 87131-1376, under contract F29601-87-C-0001, for the Engineering and Services Laboratory, Air Force Engineering and Services Center, Tyndall Air Force Base, Florida 32403-6001. (The name was changed to the Air Force Civil Engineering Support Agency on 1 August 1991). The report summarized work done between May 1990 and April 1991. The HQ AFCESA/RACF Project Officer was Capt John R. Floden.

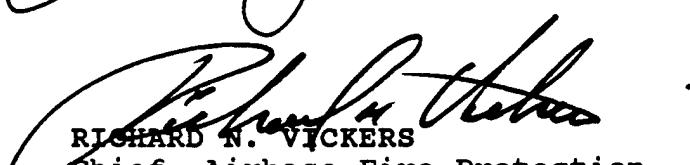
This report has been reviewed by the Public Affairs Officer(PA) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public, including foreign nationals.



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## LIST OF ABBREVIATIONS

AFB	.....	Air Force Base
AFR	.....	Air Force Regulation
CAA 1990	.....	Clean Air Act Amendments of 1990
CFC	.....	Chlorofluorocarbon
CY	.....	Calendar Year
DOD	.....	Department of Defense
EPA	.....	Environmental Protection Agency
GOCO	.....	Government-owned Contractor-operated
GWP	.....	Global Warming Potential
HBFC	.....	Hydrobromofluorocarbon
HCFC	.....	Hydrochlorofluorocarbon
HFC	.....	Hydrofluorocarbon
HQ	.....	Headquarters
HQ USAF/LEE	.	Headquarters United States Air Force, Engineering and Services*
MAC	.....	Mobile Air Conditioner
MILSPECs	....	Military Specifications
MILSTDs	....	Military Standards
ODP	.....	Ozone Depletion Potential
R/R/R	.....	Recovery/Recycle/Reclamation
SAE	.....	Society of Automotive Engineers
UL	.....	Underwriters Laboratories
USAF	.....	United States Air Force
UV	.....	Ultraviolet

\*Changed to the AF/CE...Air Force Civil Engineer on 1 August 1991.

## SECTION I

### INTRODUCTION

#### A. OBJECTIVE

The overall objective of this project was to assess the impact on the United States Air Force (USAF) of national and international restrictions on the production and consumption of chlorofluorocarbons (CFCs), halons, and other substances believed to contribute to stratospheric ozone depletion.

#### B. BACKGROUND

Increasing scientific evidence shows that manmade substances released into the atmosphere are causing depletion of ozone levels in the stratosphere. The concentration of stratospheric ozone begins at approximately 10 miles and extends to approximately 35 miles above the earth's surface and acts as a shield for the earth by screening out excessive amounts of the sun's ultraviolet (UV) radiation, which can be harmful to life. Potential biological effects include increases in incidences of skin cancer and cataracts, inability to resist certain infectious diseases, decreased yields of agricultural crops, and impacts on marine life essential to the food chain.

Growing worldwide concern over stratospheric ozone depletion has led to an international agreement (Montreal Protocol) to phase out chlorofluorocarbon and halon consumption (defined as production minus exports plus imports) by the year 2000. The chlorofluorocarbons are widely used as refrigerants (in mobile air-conditioners, stationary refrigeration and air-conditioning units), cleaning solvents, sterilants, foam-blowing agents, and aerosol propellants. Halons are used primarily as effective and clean fire- and explosion-suppression agents. The phaseout of these compounds will cause a significant impact on both industrialized nations and emerging nations. A massive effort,

already under way, is required to find alternative compounds, equipment, and processes to replace CFCs and halons by the year 2000.

#### C. SCOPE/APPROACH

This assessment includes substances regulated by the Montreal Protocol, as well as all other substances suspected of being stratospheric ozone depleters now in use or planned for future use by the USAF. This assessment is based on a HQ USAF/LEE inventory of USAF ozone-depleting substances, including end-use identification, conducted for calendar year (CY) 1989.

An in-depth technology assessment was conducted to identify alternative compounds, availability dates, whether they are "drop-in" replacements or require new hardware/systems, and, when possible, projected cost impacts to the USAF. The inventory and end-use data were used to assess the impact of the phaseout schedule of CFCs and halons on USAF operations, with emphasis on mission-critical categories.

## SECTION II

### REGULATORY RESTRICTIONS

#### A. BACKGROUND

Public concern over depletion of stratospheric ozone became focused following a 1974 article in Nature by M. J. Molina and F. S. Rowland, who proposed that chlorine from CFCs could destroy stratospheric ozone and thus increase the amount of UV light reaching the earth's surface (Reference 1). In 1978, the U.S. banned the use of CFCs in nonessential aerosol products because of concerns that their use would deplete the protective stratospheric ozone. In spite of this control, the global production of CFCs continued to rise. The United Nations Environment Programme (UNEP) developed an international framework to protect stratospheric ozone at the 1985 Vienna Convention.

#### B. MONTREAL PROTOCOL ON SUBSTANCES THAT DEPLETE THE OZONE LAYER

Following the UNEP Vienna Convention, representatives of the U.S. and 24 other nations convened in Montreal, Canada in September 1987 and signed an international treaty, the Montreal Protocol on Substances that Deplete the Ozone Layer (Montreal Protocol). More than 60 nations, representing over 90 percent of the world's production of CFCs and halons, have now ratified the treaty (Reference 2). The treaty became effective on 1 January 1989 and limited consumption (defined as production minus exports plus imports) of CFC-11, -12, -113, -114, and -115 to 1986 levels by 1 July 1989. In addition, it required a 20 percent cut in consumption levels by 1993 and an additional 30 percent, by 1998. Halons 1211, 1301, and 2402 were handled in a separate group with a freeze on production by 1992 to 1986 levels (Reference 3). On 12 August 1988, the U.S. Environmental Protection Agency (EPA) under authority of section 157(b) of the Clean Air Act, promulgated a final rule implementing the control measures called

for in the Montreal Protocol and allocating production allowances to companies proportional to their 1986 production and import levels (Reference 2).

The Omnibus Budget Reconciliation Act of 1989 placed an excise tax on the sale of chemicals that deplete the ozone layer. This tax does not apply to recycled materials and thus provides an incentive for recycling controlled substances and makes higher priced substitutes more competitive. The tax is assessed on each pound sold or used by a manufacturer, producer, or importer. The amount of tax is equal to a base amount multiplied by the ozone-depletion potential (ODP) of the chemical (as stated by the Montreal Protocol) multiplied by the number of pounds sold. The base tax for CFCs began at \$1.37 per pound in 1990 and 1991, will rise to \$1.67 per pound in 1992, \$2.65 per pound in 1993 and 1994, and then increase by \$0.45 per pound each year after 1994. Halons were exempted from the tax in 1990, taxed at \$0.25 per pound in 1991 through 1993, and then taxed at \$2.65 per pound multiplied by their ODP beginning in 1994. For example, Halon 1301 with an ODP of 10.0, will be taxed at \$26.50 per pound beginning in 1994. The excise tax structure is depicted graphically for CFCs and halons in Figures 1 and 2, respectively.

Increasing scientific evidence that ozone depletion was more extensive than had been predicted resulted in a move toward more stringent regulations on ozone-depleting substances. The parties to the Montreal Protocol, meeting in Helsinki, Finland in May 1989, signed the nonbinding Helsinki Declaration, which called for complete phaseout of CFCs and halons as soon as possible but not later than the year 2000. They also called for limits on other ozone-depleting chemicals, such as carbon tetrachloride and methyl chloroform, as soon as feasible (Reference 2). Due to heightened concerns about ozone depletion, the original reassessment and revision schedule of the Montreal Protocol was accelerated. A meeting of the parties to the Protocol was held in London, England in June 1990, and the Protocol was revised. Under the revised version, the production of CFCs and halons is to be completely phased out by the year 2000.

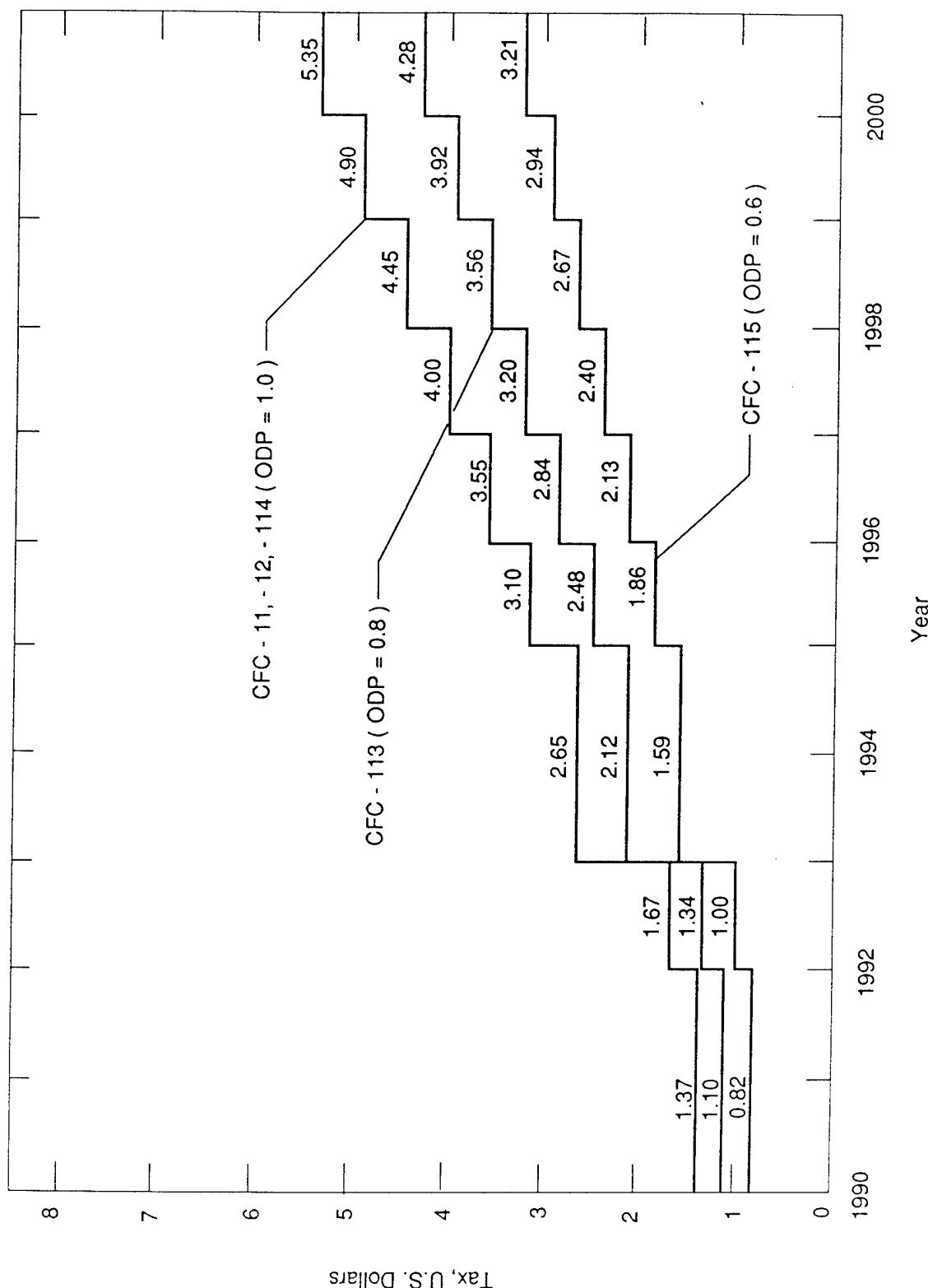


Figure 1. U.S. Tax Imposed on Manufacturers and Importers Who Sell CFCs.

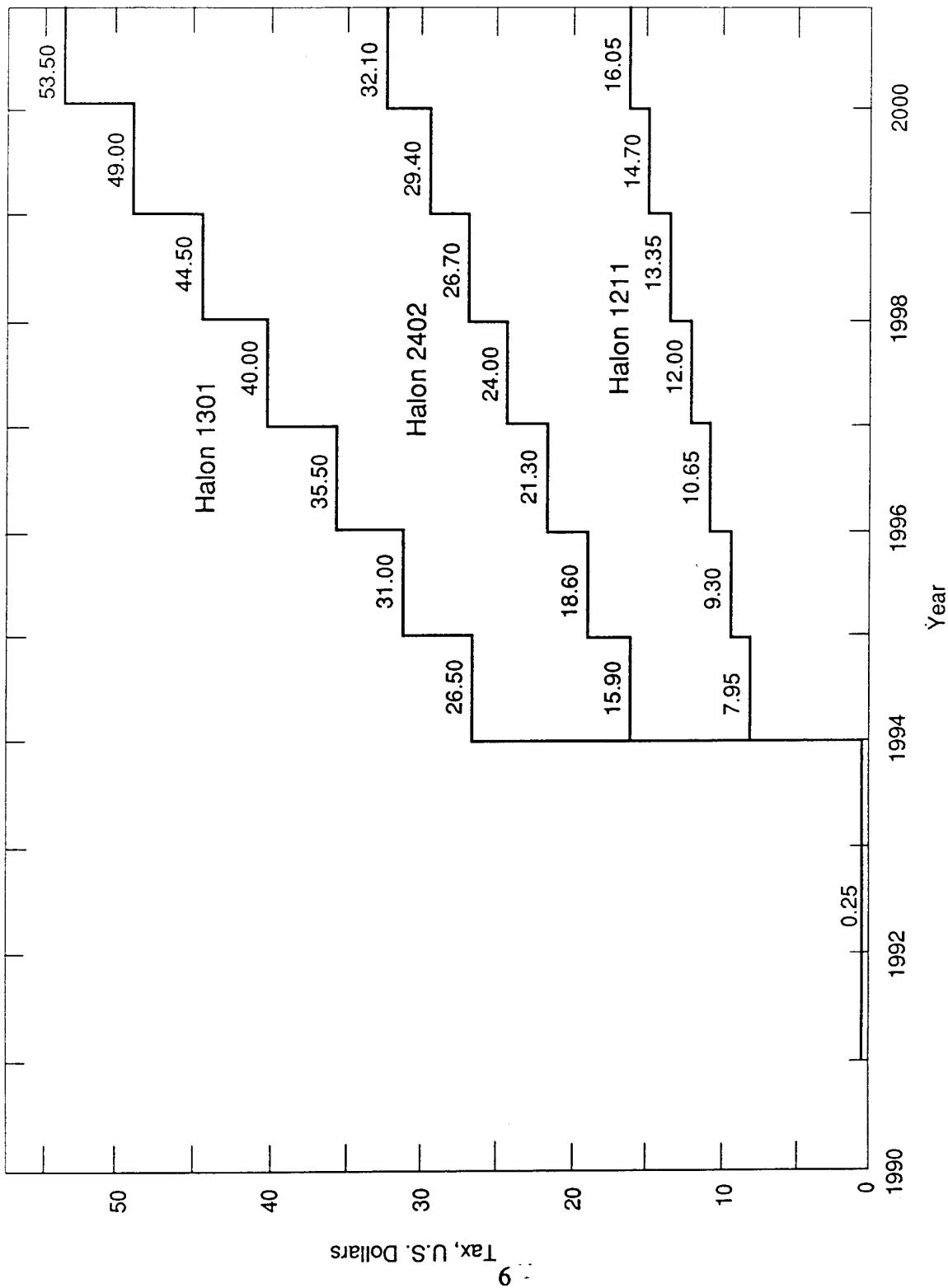


Figure 2. U.S. Tax Imposed on Manufacturers and Importers Who Sell Halons.

In addition, methyl chloroform, carbon tetrachloride, and hydrochlorofluorocarbons(HCFCs) were added to the control schedule. A comparison of the original and revised protocols is shown in Table 1.

#### C. CLEAN AIR ACT AMENDMENTS OF 1990

The Clean Air Act Amendments of 1990 (CAA 1990) were enacted by the 101st U.S. Congress in October 1990. Title VI of the CAA 1990, entitled "Stratospheric Ozone Protection," implements the restrictions of the revised Montreal Protocol and in some cases is more restrictive. The CAA 1990 designates ozone-depleting substances in Class I and Class II listings. The Class I listing is further broken down in Groups I through V. Table 2 lists the substances controlled by the Act according to Class and Group (Reference 4).

The ozone-depletion characteristics of substances vary and are based on properties such as atmospheric lifetime, the number of bromine and chlorine atoms and the ability of the substance to be disassociated photolytically. The ODP is a measure of the potential of a substance to destroy ozone in the stratosphere as compared to CFC-11, which is assigned an ODP of 1.0. ODPs are usually calculated using computer models. The results of the calculated ODPs vary slightly with the models used. The ODPs of all the Class I and a few of the Class II substances are listed in the CAA 1990. The values are consistent with those specified in the Montreal Protocol and are included here in Table 3 (Reference 4).

##### 1. Phaseout of Class I and II Substances

The restrictions on production and consumption of ozone-depleting substances under the CAA 1990 match, or are more restrictive than those of the revised Montreal Protocol. Limitations on production of ozone-depleting substances under the CAA 1990 are shown in Table 4.

TABLE 1. COMPARISON OF 1987 MONTREAL PROTOCOL  
AND THE 1990 REVISIONS.

Ozone-Depleting Chemicals	Consumption Controls under 1987 Protocol	Consumption Controls under 1990 Revision
CFCs-11, -12, -113, -114, -115	frozen at 1986 levels in July 1989; reduced to 80% by 1993; reduced to 50% by 1998.	frozen at 1986 levels in July 1989; reduced to 80% by 1993; reduced to 50% by 1995; reduced to 15% by 1997; phased out by 2000.
Halons 1211, 1301, 2402	frozen at 1986 levels by 1992	frozen at 1986 levels by 1992; phased out by 2000 with exemptions for essential uses.
Other fully halogenated CFCs	no controls	baseline year is 1989 - reduced to 80% by 1993; reduced to 15% by 1997; phased out by 2000
Carbon tetrachloride	no controls	baseline year is 1989 - reduced to 15% by 1995; phased out by 2000
methyl chloroform	no controls	frozen at 1989 levels by 1993; reduced to 70% by 1995; reduced to 30% by 2000; phased out by 2005
HCFCs	no controls	restricting use to areas where other alternatives not feasible; phased out by 2020 if feasible, but no later than 2040.

TABLE 2. LISTING OF CLASS I AND CLASS II SUBSTANCES,  
CLEAN AIR ACT AMENDMENTS OF 1990.

---

CLASS I

GROUP I

CFC -11, -12, -113, -114, -115

GROUP II

Halons 1211, 1301, 2402

GROUP III

CFC-13, -111, -112, -211, -212, -213, -214, -215, -216, -217

GROUP IV

carbon tetrachloride

GROUP V

methyl chloroform

Note: Isomers of the above substances are included except for  
1,1,2-trichloroethane (an isomer of methyl chloroform).

CLASS II

HCFC -21, -22, -31, -121, -122, -123, -124, -131, -132, -133, -141, -142, -221, -222,  
-223, -224, -225, -226, -231, -232, -233, -234, -235, -241, -242, -243, -244, -251, -252,  
-253, -261, -262, -271

Note: Isomers of the above substances are included.

---

TABLE 3. OZONE DEPLETION POTENTIALS.

Substance	ODP
CFC-11	1.0
CFC-12	1.0
CFC-13	1.0
CFC-111	1.0
CFC-112	1.0
CFC-113	0.8
CFC-114	1.0
CFC-115	0.6
CFC-211	1.0
CFC-212	1.0
CFC-213	1.0
CFC-214	1.0
CFC-215	1.0
CFC-216	1.0
CFC-217	1.0
Halon 1211	3.0
Halon 1301	10.0
Halon 2402	6.0
carbon tetrachloride	1.1
methyl chloroform	0.1
HCFC-22	0.05
HCFC-123	0.02
HCFC-124	0.02
HCFC-141b	0.1
HCFC-142b	0.06

TABLE 4. STRATOSPHERIC OZONE PROTECTION CONTROLS OF THE U.S. CLEAN AIR ACT AMENDMENTS OF 1990.

Ozone-Depleting Chemicals	Baseline Year	Production Controls	
		January of Year	Percent of Baseline Year
<b>Class I Substances</b>			
Group I		1991	85
CFCs-11, -12, -113, -114, -115	1986	1992	80
		1993	75
Group II	1986	1994	65
Halons 1211, 1301, 2402		1995	50
Group III	1989	1996	40
CFCs-13, -111, -112, -211, -212,		1997	15
-213, -214, -215, -216, -217		1998	15
		1999	15
		2000	phased out
Group IV	1989	1991	100
carbon tetrachloride		1992	90
		1993	80
		1994	70
		1995	15
		1996	15
		1997	15
		1998	15
		1999	15
		2000	phased out
Group V	1989	1991	100
methyl chloroform		1992	100
		1993	90
		1994	85
		1995	70
		1996	50
		1997	50
		1998	50

TABLE 4. STRATOSPHERIC OZONE PROTECTION CONTROLS OF THE U.S. CLEAN AIR ACT AMENDMENTS OF 1990 (CONCLUDED).

Ozone-Depleting Chemicals	Baseline Year	Production Controls	
		January of Year	Percent of Baseline Year
<b>Class I Substances (continued)</b>			
Group V	1999	50	
methyl chloroform	2000	20	
(continued)	2001	20	
	2002	phased out	
<b>Class II Substances</b>			
HCFCs-21, -22, -31, -121, -122, -123, -124, -131, -132, -133, -141, -142, -221, -222, -223, -224 -225, -226, -231, -232, -233, -234, -235, -241, -242, -243, -244, -251, -252, -253, -261, -262, -271	(to be selected by the adminis- trators of EPA not later than 31 Dec 1999)	2015 2030	100 phased out

## 2. Exceptions for Essential Uses

The CAA 1990 provides for exceptions to the production and consumption limitations for essential uses of both Class I and Class II substances.

The exceptions for Class I substances are for essential uses of methyl chloroform, for use of Class I substances in medical devices, for use of halons and methyl chloroform for aviation safety, use of Class I substances in developing countries that are parties to the Montreal Protocol, uses critical to national security, and uses for fire suppression and explosion prevention where adequate substitutes are not available.

Exceptions for Class II substances are for use in medical devices and for basic domestic needs of developing countries that are parties to the Montreal Protocol. Time periods and caps on production and use for these exceptions are specified. A listing of the exceptions with brief descriptions are shown in Table 5.

## 3. National Recycling and Emission Reduction Program

The Act also includes provisions for a National Recycling and Emission Reduction Program. Regulations are required by 1 Jan 1992, to be effective no later than 1 July 1992. The regulations establish standards for use and disposal of Class I substances during the service, repair, or disposal of appliances and industrial process refrigeration. Within 4 years after enactment of the CAA 1990, regulations will be promulgated, to be effective no more than 12 months later, that establish standards and requirements regarding use and disposal of Class II substances during service, repair, or disposal of appliances and industrial process refrigeration. The regulations in this category will contain requirements to reduce the use and emissions of Class I and II substances to the lowest achievable level and to maximize the recapture and recycling of such substances. The CAA 1990 makes further stipulations for the safe disposal of Class I and II substances. It states that regulations will be established to require that Class I

TABLE 5. EXCEPTIONS UNDER CLEAN AIR ACT AMENDMENTS OF 1990.

Category	Period	Exception	Substance	Cap on Exception	Remarks
<b>Class I Substances</b>					
1. Essential Uses of Methyl Chloroform	1 Jan 2002 - 1 Jan 2005	Authorizes the production of limited quantities of methyl chloroform in essential applications (such as nondestructive testing for metal fatigue and corrosion of existing airplane engines and airplane parts susceptible to metal fatigue) for which no safe and effective alternative is available.	Methyl chloroform	Annual quantities limited to 10% of baseline year for subcategories 1, 2, 3.	Report to Congress required in 1998 if FAA Administrator in consultation with EPA Administrator determines that further exception after 1 Jan 2005 will be necessary.
2. Medical Devices		Authorizes production of limited quantities of Class I substances solely for use in medical devices.	Class I		
3. Aviation Safety		Authorizes the production of limited quantities of Halons 1211, 1301, and 2402 solely for purposes of aviation safety where no safe and effective substitute has been developed.	Halons 1211, 1301, 2402		

TABLE 5. EXCEPTIONS UNDER CLEAN AIR ACT AMENDMENTS OF 1990 (CONTINUED).

Category	Period	Exception	Substance	Cap on Exception	Remarks
4. Developing Countries	Terminates 1 Jan 2010 (2012 for methyl chloroform)	Authorizes the production of limited quantities of Class I substances solely for export to, and use in, developing countries that are parties to the Montreal Protocol operating under Article 5 solely for satisfying basic domestic needs.	Class I	Annual quantities limited to 10% of baseline year.	Annual quantities produced; under all exceptions not to exceed 15% of baseline year for any producer.
5. National Security	Not to exceed one year	The U.S. President may issue orders regarding production and use at any specified site or facility or on any vessel as may be necessary to protect the National Security interests of the U.S. if adequate substitutes are not available.	CFC-114, Halons 1211, 1301, 2402		Must be consistent with the Montreal Protocol. Congress must be notified within 30 days with justification. Exemption period may not exceed one year, but can be renewed in one-year periods.
6. Fire Suppression and Explosion Prevention	Expires 31 Dec 1999	Authorizes production of limited quantities of Halons 1211, 1301, 2402 solely for fire suppression and explosion prevention if no safe and effective substitutes have been developed.	Halons 1211, 1301, 2402	3% of baseline year for subcategory 6.	The Administrator EPA must monitor and assess efforts to obtain substitutes and report to Congress in 1994 and in 1998.

TABLE 5. EXCEPTIONS UNDER CLEAN AIR ACT AMENDMENTS OF 1990 (CONCLUDED).

Category	Period	Exception	Substance	Cap on Exception	Remarks
Fire Suppression and Explosion Prevention (continued)	31 Dec 1999 to 31 Dec 2004	Authorizes production of limited quantities of Halons 1211, 1301, and 2402 solely for fire suppression and explosion prevention of facilities for domestic production of crude oil and natural gas on the North Slope of Alaska if no safe and effective substitutes have been developed.	Halons 1211, 1301, 2402		
Class II Substances					
1. Medical Devices		Authorizes production and use of limited quantities of Class II substances solely for use in medical devices.	Class II	10% of baseline year	
2. Developing Countries	1 Jan 2015 to 1 Jan 2030	Authorizes production of limited quantities of Class II substances solely for export and use for basic domestic needs in developing countries that are parties to the Montreal Protocol.	Class II	110% of baseline year	
	1 Jan 2030 to 1 Jan 2040			15% of baseline year	

and II substances contained in bulk in appliances, machines, or other goods be removed prior to disposal or delivery for recycling. The regulations will also require appliances containing Class I and II substances to be manufactured with a service aperture or other effective design feature to facilitate recapture of such substances during service, repair, or disposal. Finally, under this section of the CAA 1990, effective 1 July 1993, it will be unlawful for any person in the course of maintaining, servicing, repairing, or disposing of an appliance or industrial process refrigeration, to knowingly vent or otherwise knowingly release any Class I or II substance permitting it to enter the environment. By October 1995, it will be unlawful to vent or release any Class I or II substitute substance used in the manner outlined previously.

#### 4. Servicing of Motor Vehicle Air-Conditioners

Use of CFC-12 in mobile air-conditioners (MACs) is estimated at 28 percent of global CFC-12 production (Reference 5). The world consumption of CFC-12 for MACs was estimated at 12 ODP-weighted percent for 1986 (Reference 6). Because of the release of CFC-12 from MAC servicing and the impact on ozone depletion, plus the relative maturity of recovery and recycling technology for MACs, the CAA 1990 set some early dates for the industry to meet for recovery. It specifies that by 1 Jan 1992 no person repairing or servicing motor vehicles for consideration may perform any service on a motor vehicle air-conditioner involving the refrigerant without being properly trained and certified and properly using approved refrigerant recycling equipment. This requirement will not apply until 1 Jan 1993 for entities that repaired or serviced fewer than 100 automobiles in 1990.

#### D. DEPARTMENT OF DEFENSE REQUIREMENTS

The Department of Defense (DOD) started evaluating its use of CFCs and halons in 1987 when it appeared that their future use might be limited. DOD concluded that many of its uses of CFCs and halons were similar to those in the private sector; however,

there were also many military applications that were unique and had no civilian equivalent. After the Montreal Protocol was signed in September, 1987, the Office of the Secretary of Defense issued DOD Directive 6050.9 (Reference 7) to establish policy and assign responsibility for the following:

1. The management of CFCs and halons in DOD;
2. The identification of CFC and halon applications and prioritization of their uses;
3. The long-term process of decreasing DOD dependence on CFCs and halons because of reduced availability in future years as a result of recently promulgated international and domestic production limits;
4. Research and development programs to develop or evaluate suitable substitutes for halons and other mission-critical CFC applications; and
5. A tracking system to document the annual DOD requirements for CFCs and halons.

The National Defense Authorization Act for fiscal years 1990-1991 directed DOD to institute a program to reduce emissions of CFCs (Reference 8). This public law required DOD to report back to Congress on progress in reducing emissions of CFCs and halons in two reports. The first report was to

1. Specify emission reduction goals, that are attainable through the application of current technology, to reduce unnecessary release of CFCs and halons in connection with operations, training and testing practices of the DOD;
2. Assess the potential for new technologies to obtain significant reductions in CFC and halon use; and
3. Estimate the investments required to attain specific goals over a 5-year period.

The second report was to address implementation issues in administering long-term CFC and halon reductions, as well as the prospects of developing substitutes or alternative technologies as part of a long-term strategy to eliminate their use (Reference 9).

The Department of Defense has created a CFC and halon phaseout schedule, which includes short-term reductions in unnecessary emissions and long-term reductions in CFC and halon use. DOD has prioritized current end uses and categorized them into the three groups defined below (Reference 9).

#### Category I: Mission Critical Use

The highest priority uses are those that are mission critical. Mission-critical uses have a direct impact on combat mission capability and include uses integral to combat mission assets or affect operability of these assets. Mission-critical uses include cooling operational assets and charging fire and explosion suppression systems onboard aircraft, vehicles, and vessels to protect those assets and mission critical personnel.

#### Category II: Essential Use

Essential uses include those applications that have an indirect effect on combat mission assets and play an auxiliary role in ensuring the operability of those assets. Essential uses include process cooling applications and charging portable fire extinguishers for area protection of electronics.

#### Category III: Nonessential Use

This category includes all nonessential uses. Nonessential uses include uses for comfort cooling in family and troop housing and installation support activities.

A schedule that establishes goals for reduction (and ultimately elimination of CFC and halon releases) procurement and use was developed by DOD (Reference 9). The schedule is outlined in Table 6. Intermediate reduction goals can most likely be

TABLE 6. DOD GOALS FOR REDUCTION IN CFC AND HALON RELEASES,  
PROCUREMENT, AND USE.

Institute plans to reduce unnecessary releases during use	Institute plans to eliminate procurement and use	Stop use in new procurements	Phaseout of current applications to zero 50 percent of 1986 levels	Reduce use in all applications to zero
Milestones for CFCs:				
Mission Critical (Category I)	Oct 90	Oct 93	Oct 98	Oct 98
Mission Essential (Category II)	Oct 90	Oct 93	Oct 97	Oct 97
Nonessential (Category III)	Oct 90	Oct 92	Oct 96	Oct 96
Milestones for Halons:				
Mission Critical (Category I)	Oct 90	Oct 90	Oct 95	Oct 95
Mission Essential (Category II)	Oct 90	Oct 90	Oct 90	Oct 95
Nonessential (Category III)	Oct 90	Oct 90	N/A	Oct 95

achieved by conservation practices, recovery and recycling, and use of alternative processes. Total phaseout, however, depends on development of adequate replacements and adaption of them to existing systems, or the adoption of alternate processes to perform the same function.

In order to implement the requirements of DOD Directive 6050.9, reduce emissions of CFCs and halons, and phaseout their use as soon as feasible, the USAF developed Regulation 19-15, which has recently been finalized. This regulation calls for implementation of conservation measures, such as recovery and recycling, and modification of testing and training practices so that discharges to the atmosphere can be reduced to zero as soon as possible (Reference 10). It adopts the end-use category definitions specified by the DOD and the goals for release reduction and phaseout. In addition it requires the Air Force to accomplish the following:

1. Develop procedures to identify use requirements and the quantities that are available or banked in systems or stored reserves; develop reporting procedures to satisfy the requirements of DOD Directive 6050.9 and the U.S. Congress.
2. Set up procedures to redirect reserve quantities to applications in the most critical use categories.
3. Identify mission-critical end uses that are essential in national security and life-threatening situations for which replacement substances or alternate techniques are not available now or in the near future.
4. Ensure compliance by overseas installations with these requirements as well as with other U.S. treaty obligations.

### SECTION III

#### USAF USE OF OZONE-DEPLETING SUBSTANCES

The USAF, the other military services, and the civilian sector have become heavily dependent on CFCs, halons, and other ozone-depleting substances to perform a variety of functions. Most of the uses such as refrigeration, comfort air-conditioning, solvent cleaning, and fire extinguishing are comparable in the military and civilian sectors. Alternate processes or replacement substances can be more easily found for noncritical applications.

Some military applications of ozone-depleting substances are unique and essential to the defense mission and thus fall into the mission-critical use category. Some examples for combat-related halon fire suppression are aircraft engine nacelles, aircraft crew compartments, tactical ground vehicles, ships, and command, control and communication centers. Essential uses for CFCs include solvent cleaning of critical electronic components and optical surfaces and cooling of shipboard weapon and electronic systems.

The general approach taken by DOD is to rely on the innovations and efforts of private industry for replacement substances and alternate technologies for nonessential applications. In mission-critical and essential areas, DOD is taking a more active role in research and development of alternatives (Reference 9).

#### A. INVENTORY SURVEY

The initial approach for an inventory survey of USAF-wide use of CFCs and halons was to do a end-use inventory survey of one or more USAF bases and then project that sample data to USAF-wide application. The effort began at Kirtland AFB in Albuquerque, New Mexico.

Contact was made initially with the Base Environmental Management office to find out whether centralized reports on CFC and halon inventory and use were available. Although the staff remembered providing input to the 1989 USAF use survey, input records were not on file. The next contact was with the Bioenvironmental Engineering Services office. They do not do CFC and halon inventory or emission reports but instead generate an annual emissions report that includes some CFCs and halons. They also produce inventory reports on Air Force Form 2761, which includes hazardous materials and usage rates. Inventories are completed for each of the 230 work centers at Kirtland AFB. A review of these forms might reveal some though not all of the CFC and halon usage.

The Base Supply Office was contacted to determine whether records existed on the purchase of CFCs and halons. Because of limited space on their computer, the records were not kept longer than one month, and no hard copy records were filed.

The Fire Protection Branch was contacted to find out whether they maintain records on halon purchase and use. Although no directives require them to do so, this particular office does retain records on the Halon 1211 purchased. Those figures were reported for the 1989 use and inventory survey but were no longer on file. No records on Halon 1301 procurement and use were kept since the Base Civil Engineering office has open contracts for direct local purchase of Halon 1301 for installed systems when the need arises.

Based on the attempt to survey end use and inventory of CFCs and halons on Kirtland AFB, it was concluded that it would be labor-intensive and expensive to obtain meaningful Air Force wide data. The data gathered might also have questionable accuracy in the absence of centralized requirements to keep records and report CFC and halon usage. As a result of the reporting requirements of DOD Directive 6050.9, however, that situation will change in the near future. In fact, Air Force Regulation (AFR) 19-15 will put in place the mechanisms to ensure accurate annual reporting of

CFC and halon use on a consistent basis. AFR 19-15 requires that all Major Commands develop procedures for gathering accurate data on quantities of CFCs and halon procured, stored or emitted and reporting that data to HQ USAF by 1 March each year. AFR 19-15 has not yet been approved, but is scheduled to be released and take effect soon. In the meantime, estimates of CFC and halon use have been provided to HQ USAF to meet the reporting requirements of the U.S. Congress, committees on Armed Services. The first report to Congress, submitted in July 1990 for calendar year 1989, contains the best information available, at this time, for CFC and halon uses in the Services (Reference 9).

## B. END-USE IDENTIFICATION

To standardize CFC- and halon-use data collected within the service components, DOD defined consumption and eight end-use categories as follows (Reference 9):

1. Consumption: CFCs and halons purchased in bulk by DOD to maintain existing equipment or use in new equipment; CFCs and halons used by government-owned contractor-operated (GOCO) facilities that provide equipment or services to DOD.
2. End-Use Categories
  - a. Large refrigeration and air-conditioning -- includes cold storage, retail food refrigeration, and refrigeration systems used in industrial processes, chillers, and buildings.
  - b. Mobile Air-Conditioners (MACs) -- passenger cooling in automobiles and cabs of all trucks and includes initial and replacement charges of CFCs.
  - c. Household refrigeration -- includes home refrigerators, freezers, and other small appliances such as ice machines and dehumidifiers.

- d. Solvent cleaning -- includes the cleaning of metals, optics, electronics, automotive electrical systems, and printed circuit boards.
- e. Foams -- CFCs used as foam-blown agents in the production and installation of insulation, foams, and packaging materials.
- f. Sterilization -- CFC-12 as used to dilute ethylene oxide in sterilization processes to reduce flammability and explosion risks.
- g. Miscellaneous -- includes aerosols, optical coatings, specialized cooling applications, and gyroscopes.
- h. Halon fire extinguishing equipment -- as used in portable extinguishers (Halon 1211) and installed systems (Halon 1301).

The data shown in the following tables were derived from Reference 9. It is labeled "estimated" since the tracking and reporting systems of the services are not mature and some estimations had to be made.

The estimated 1989 individual Service and DOD total use of CFCs and halons is shown in Table 7. Note that the Air Force used 1664 metric tons (39.1 percent) of the total DOD CFCs and 415.6 metric tons (34.3 percent) of the halons. Tables 8 and 9 show the estimated 1989 DOD CFC and halon uses, respectively, by end use for each compound by each Service and the DOD totals. Table 10 shows the estimated total 1989 CFC and halon use by compound for each of the Services and the DOD totals.

Note that the Services and DOD reported use of R-500 and R-502, which are not specifically regulated by the Montreal Protocol or CAA 1990, but are blends containing regulated CFCs. R-500 is an azeotropic blend of 74 weight percent of CFC-12 and 26 weight percent of hydrofluorocarbon (HFC)-152a. R-502 is an azeotropic blend of 49 weight percent of HCFC-22 and 51 weight percent of CFC-115. The CFC-12 in R-500 and the CFC-115 in R-502 are regulated CFCs.

TABLE 7. 1989 ESTIMATED DOD CFC AND HALON USE.

Military Service	Amount Used (Metric Tons)	Portion of Total DOD Use, %	Use Services Listed As Mission Critical, %	Use Services Listed As Essential, %	Use Services Listed As Nonessential, %
1989 Estimated DOD CFC Use:					
Air Force	1664	39.1	23	61	16
Army	779	18.3	0	46	54
Navy	1812	42.6	46	42	12
DOD Totals	4255	100	29	50	21
1989 Estimated DOD Halon Use:					
Air Force	416	34.3	76	24	0
Army	402	33.2	1	99	0
Navy	406	32.5	91	9	0
DOD Totals	1212	100	56	44	0

TABLE 8. 1989 ESTIMATED DOD CFC USE BY END USE (METRIC TONS).

Military Service	Commercial Refrigeration				Household Solvents				Household Sterilization				Household Foams				Miscellaneous			
	CFC-11 CFC-12 CFC-114 CFC-115			R-502	CFC-11 CFC-12 CFC-113				CFC-11 CFC-12 CFC-113				CFC-11 CFC-12 CFC-113				CFC-114 R-500 R-502			
	Elect.	Mech.	Elect.	Mech.	Elect.	Mech.	Elect.	Mech.	Elect.	Mech.	Elect.	Mech.	Elect.	Mech.	Elect.	Mech.	CFC-114	R-500	R-502	
Air Force	63	150	0	2.3	0.45	0.5	6.0	33	0	395	909	3	77	13	114	0.5	0.2	0.05		
Army	252	70	4.5	3.4	0	0	0	0	0	251.1	107	5	87	0	0	0	0	0		
Navy	68	615.7	149.2	1.8	0	0	0	0	0	670	287.3	19	0	0	0	0	0	0		
DOD Totals	383	835.7	153.7	7.5	0.45	0.5	6.0	33	0	1316.1	1303.3	27	164	13	114	0.5	0.2	0.05		

TABLE 9. 1989 ESTIMATED DOD HALON USE BY END USE (METRIC TONS).

Military Service	END USE				Portable 1301 Electrical	Portable 1211 Flam. Liquid	Other	Portable 1301 Electrical				
	Total-Flood 1301											
	Electrical	Flam.	Liquid									
Air Force	85	0	7	19	198	93	14					
Army	181	42	0.7	73	32	73	0					
Navy	272.5	30.3	0	45.5	0	45.5	0					
DOD Totals	538.5	72.3	7.7	137.5	230	211.5	14					

TABLE 10. 1989 ESTIMATED DOD CFC AND HALON USE BY COMPOUND (METRIC TONS).

Military Service	CFCs					Halons					
	11	12	113	114	500	502	Totals	1211	1301	Totals	
Air Force	80.9	276	1304	0.5	2.3	0.2	0.5	1664.4	310	106	416
Army	252	162	358.1	4.5	3.4	0	0	780	178	223.8	401.8
Navy	68	634.7	957.3	149.2	1.8	0	0	1811	91	302.8	393.8
DOD Totals	400.9	1072.7	2619.4	154.2	7.5	0.2	0.5	4255.4	579	632.6	1211.6

### C. CRITICAL-USE CATEGORY

Each of the Services reported its uses of CFCs and halons according to the mission-critical, essential, and nonessential end-use category definitions previously presented. The 1989 estimated DOD and Services uses of CFCs and halons by compound and by criticality categories are shown in Tables 11 and 12. The Air Force listed 382.7 metric tons of CFCs, 39.1 percent of Air Force uses, as mission critical, (Table 13). The Air Force listed 315.8 metric tons or 76 percent of their halon uses as mission critical (Table 13). No DOD uses of halons were listed by any Service as nonessential.

TABLE 11. 1989 ESTIMATED DOD CFC USE BY COMPOUND AND BY CRITICALITY (METRIC TONS).

Category	CFCs					Total by Criticality for Service and DOD					
	11	12	113	114	115	500	502	Air Force	Army	Navy	DOD
Mission Critical (I)	78	423	566	150	0	0	0	382.7	0	833.5	1216.2
Essential (II)	6.3	65.9	2053.5	0	0	0	0	1015	358.3	761	2134.3
Nonessential (III)	311.1	584.1	0	4.5	7.5	0.2	0.05	266.3	420.7	217.5	904.5
Totals	394.9	1072.7	2619.8	154.2	7.5	0.2	0.05	1664	779	1812	4255

TABLE 12. 1989 ESTIMATED DOD HALON USE BY COMPOUND AND BY CRITICALITY (METRIC TONS).

Category	Halons		Total By Criticality for Service and DOD			DOD
	1211	1301	Air Force	Army	Navy	
Mission Critical (I)	319	360.6	315.8	4	358.3	679.6
Essential (II)	260	272	99.8	398.2	35.5	532
Nonessential (III)	0	0	0	0	0	0
Totals	579	632.6	415.6	402.2	393.8	1211.6

## SECTION IV

### TECHNOLOGY ASSESSMENT FOR CFC AND HALON REPLACEMENTS AND ALTERNATIVES

This section addresses the state of technologies to mitigate the phaseout of CFC and halon use within the USAF. The term "replacement" is used to designate a new compound that will perform essentially the same function and can replace a CFC or halon that is being phased out under the requirements of the Montreal Protocol and CAA 1990. The term "alternative" designates a new process or engineering solution to use in performing the function now accomplished by the CFC or halon being phased out.

#### A. REFRIGERANTS

Refrigerants are working fluids in vapor compression cycles used to remove heat from one space and transfer it to another space. The vapor compression cycle takes advantage of a change in physical state of a working fluid brought about by the application of heat and mechanical work. To be useful as a refrigerant, the thermophysical properties of a fluid must satisfy certain requirements. Many fluids used in early refrigeration cycles were toxic and/or flammable. The current CFCs in widespread use as refrigerants were developed in the 1930s to provide safe and stable working fluids. A series of CFC fluids was developed covering a wide range of pressures. This enabled the industry to tailor hardware and refrigerants to specific applications with reliability and energy efficiency. CFC replacements which are a one-for-one match to the current applications are desired. Work is already well underway by the chemical and refrigeration industries to find such replacements. The CFCs most commonly used as refrigerants are shown in Table 13 along with potential non-CFC replacement fluids (Reference 5).

TABLE 13. FULLY HALOGENATED CFC REFRIGERANTS AND ENVIRONMENTALLY ACCEPTABLE POTENTIAL REPLACEMENTS.

Fully Halogenated CFCs			Potential Replacement Refrigerants		
Number	Formula	Normal Boiling Pt., °C	Designation	Formula	Normal Boiling Pt., °C
11	CCl <sub>3</sub> F	24	123 141b ethyl chloride propyl chloride bis(difluoromethyl) ether	CHCl <sub>2</sub> CF <sub>3</sub> CCl <sub>2</sub> FCH <sub>3</sub> C <sub>2</sub> H <sub>5</sub> Cl C <sub>3</sub> H <sub>7</sub> Cl CHF <sub>2</sub> OCHF <sub>2</sub>	27 32 12 47 5
12	CCl <sub>2</sub> F <sub>2</sub>	-30	134a 134 dimethyl ether	CF <sub>3</sub> CH <sub>2</sub> F CHF <sub>2</sub> CHF <sub>2</sub> CH <sub>3</sub> OCH <sub>3</sub>	-27 -20 -25
13	CClF <sub>3</sub>	-81	32 23	CH <sub>2</sub> F <sub>2</sub> CHF <sub>3</sub>	-52 -82
114	CClF <sub>2</sub> CClF <sub>2</sub>	4	124 142b butane isobutane	CHClFCF <sub>3</sub> CClF <sub>2</sub> CH <sub>3</sub> C <sub>4</sub> H <sub>10</sub> C <sub>4</sub> H <sub>10</sub>	-12 -9 -1 -12
115	CClF <sub>2</sub> CF <sub>3</sub>	-39	152a 134a ammonia 22	CHF <sub>2</sub> CH <sub>3</sub> CF <sub>3</sub> CH <sub>2</sub> F NH <sub>3</sub> CHClF <sub>2</sub>	-25 -27 -33 -41
502	49 weight % 22 & 51 weight % 115	-45	propane 143a 125	C <sub>3</sub> H <sub>8</sub> CF <sub>3</sub> CH <sub>3</sub> CF <sub>3</sub> CHF <sub>2</sub>	-42 -48 -48

Under the refrigerant category of CFC uses, DOD defines three separate categories: large refrigeration and air-conditioning, mobile air-conditioners, and household refrigeration (Reference 9). The technology assessments will be addressed according to the same categories.

### 1. Large Refrigeration and Air-Conditioning

This category includes cold storage, retail food refrigeration, industrial process refrigeration, and building and industrial process chillers. The Air Force reported the use of about 216 metric tons, 13 percent of Air Force use of CFCs, in this category during 1989 (Table 8). Of that total, CFC-12 use was 69.6 percent, CFC-11 was 29.2 percent, CFC-115 use was 1 percent, and R-502 was reported at 1 percent and 0.2 percent (Reference 9).

Refrigerants used for cold storage, retail refrigeration, and industrial process refrigeration are usually ammonia, CFC-12, HCFC-22, and R-502. Building and industrial process chillers generally use CFC-11 and CFC-12 with some use of HCFC-22 and R-500. CFC-114 is used almost exclusively in centrifugal chillers on Navy vessels (Reference 5).

No "drop-in" replacement refrigerants have been developed for any of these applications, and none is expected in the near future. Replacements have been developed, however, that will allow existing equipment to be used with some modifications and with only a small loss in cooling capacity or efficiency. This is very important since much of the existing equipment has a service life of 30 years or more and collectively represents a very large capital investment.

CFC-11 is used in more than two-thirds of the centrifugal chillers in the U.S. (Reference 5), although use as refrigerants represents about 29 percent of Air Force use (Reference 9). HCFC-123 has been developed as a replacement for CFC-11.

Equipment changes required to switch from CFC-11 to HCFC-123 include new gaskets and seals as well as a motor changeout in hermetic units because of incompatibility with the insulation used on the motor. Initial retrofits have shown reductions in cycle efficiency of 2 to 5 percent and also in capacity margins of 10 to 15 percent (Reference 11). Performance losses can be reduced by modifying evaporator and condenser tube surfaces. If the system now operating with a CFC has little capacity margin, retrofitting with a new refrigerant may not be the best option.

Use of HCFC-123 also requires the installation of an air monitor, alarm system, and exhaust devices in the equipment room to ensure exposure to personnel, in case of leaks, is below the 100 parts per million acceptable exposure limit. Manufacturers are currently producing chillers made for the new HCFC-123 refrigerant (Reference 12). In addition, major chiller manufacturers are working on retrofit capabilities for new refrigerants by reconditioning existing equipment at their manufacturing facilities or making field modifications (References 11 and 13). A totally reconditioned chiller to operate with HCFC-123 will cost about 65 to 75 percent of the price of a new chiller (Reference 14).

The most likely replacement for CFC-12 in many applications is HFC-134a (Reference 15). With a boiling point of -27 °C (compared to -30 °C for CFC-12), HCFC-134a is suitable for use in centrifugal and reciprocating chillers and medium temperature refrigeration and air-conditioning applications. HFC-134a is already in use in centrifugal chillers at several locations. Early projections of a switch from CFC-12 to HFC-134a indicated reduced capacities, lower efficiency, and problems with compatibility of lubricating oils (Reference 16). Life-cycle tests have shown, however, that centrifugal chillers designed for CFC-12 or R-500 can be switched to HFC-134a with little or no loss in performance. The modifications required are changing the compressor gear set to optimize speed and replacing the CFC-12 and mineral oil with HFC-134a and an ester-based synthetic oil (Reference 16). With existing R-500 machines, the switch can be made without changing the gear set. The

efficiency is about the same, but an approximate loss of 10 percent in capacity occurs. If the gear set is changed, the capacity and efficiency are essentially identical (Reference 16).

HCFC-22 is an important refrigerant in the short-term for the transition to non-CFC refrigerants. Although it has a low ozone depletion potential of 0.05, it is classified as a Class II regulated substance under the Montreal Protocol and the CAA 1990. The Montreal Protocol calls for restriction of HCFC use to areas where other alternatives are not feasible, phasing them out if possible by 2020 but no later than 2040. The CAA 1990 is more restrictive for HCFCs and calls for banning sales of HCFCs by 1 January 2015 except for HCFCs that have been used, recovered, recycled, consumed in production of other chemicals, or used as a refrigerant in appliances that have been manufactured prior to 1 January 2020. Production is then to be phased down and eliminated by 1 January 2030.

HCFC-22 can be used in both medium- and low- temperature systems instead of CFC-12 and R-502. It is estimated that HCFC-22 is used in about 10 percent of the medium temperature retail refrigeration systems globally (Reference 5). The extent of HCFC-22 use in the USAF is not known since it was not reported in the 1989 use survey except as a component in R-502; however, current USAF use is expected to be low. The importance of HCFC-22 in the short-term transition phase is that it is a proven refrigerant, and new equipment that uses HCFC-22 will have at least a 25- to 30-year availability of refrigerant. Manufacturers are producing a broader line of compressors and other system components for HCFC-22 (Reference 17). One company that rebuilt compressors over the last 2 years has been converting about 5 percent of the CFC-12 compressors to operate with HCFC-22. An evaluation of converted units after one year shows no problems (Reference 18).

The state of technology for replacement refrigerants and alternate systems and processes for large refrigeration and air conditioning appears to be available and

progressing to meet the CFC production phaseout in the year 2000. The chemical industry is building facilities for the production of HCFC-123 as a replacement for CFC-11 and HFC-134a as a replacement for CFC-12. In fact, limited production quantities are already available with full production capabilities projected within the next year. The per-pound costs are considerably higher for the replacements; however, as production increases and the yearly increasing tax is added to CFCs, prices are expected to be about the same before the mid-1990s. From that point on the replacements will be less expensive than CFCs. The cost of converting existing systems to use replacement refrigerants will vary considerably but have been estimated to range from \$100 to \$600 per ton of system capacity (Reference 19).

## 2. Mobile Air-Conditioners

Mobil Air-Conditioners (MACs) are systems for occupant cooling in automobiles and cabs of trucks. This category does not include transport refrigeration for cargo in trucks. MACs use CFC-12 as the refrigerant almost exclusively. HFC-134a is currently the replacement refrigerant of choice for MACs as it is for most other CFC-12 refrigerant applications. It is incompatible with current MAC systems, and modifying existing CFC-12 systems will not be economically feasible. Therefore, existing systems will have to rely on the availability of CFC-12 either from reduced production quotas until it is phased out in 2000 or from recovered and recycled stocks. The use of CFC-12 in MACs is estimated at 28 percent of the global CFC-12 production (Reference 5). Currently about 90 percent or more of all new cars bought in the U.S. have MACs installed. The ratio is probably much lower in USAF vehicles. The USAF has reported use of 77 metric tons of CFC-12 for MACs for 1989 (Table 9). This is only about 4.6 percent of all CFCs used by the USAF in 1989.

Automobile manufacturers are currently working on new system designs to operate with HFC-134a. One company has announced that the first models available with HFC-134a will be the 1992 models, which will be for sale in late 1991. Several

major auto companies have announced the introduction of models with HFC-134a MACs in 1992, 1993 and 1994 (Reference 20). Although auto companies have not stated when their conversion to HFC-134a will be complete, it appears that it will be 1995 at the earliest.

Since it is impractical to convert CFC-12 MACs to HFC-134a, the CFC-12 systems will have to rely on the reduced production quotas under CAA 1990 until the phaseout in 2000 or on recovered and recycled CFC-12. Automobiles are considered to have a service life of 10-11 years, so even though most new automobiles use HFC-134a MACs by 1995, there will only be a few years where CFC-12 will be required to recharge older systems before the autos become obsolete or worn out and replaced.

### 3. Household Refrigeration

Household refrigeration, as defined by the DOD (Reference 9), includes home refrigerators, freezers, and other small appliances such as ice machines and dehumidifiers. The refrigerant used in these appliances is almost exclusively CFC-12. The components and systems used have enjoyed almost 50 years of development and refinement into very efficient and reliable systems with average lifetimes of close to 20 years. The amount of CFC-12 used in the refrigeration loop ranges from about one third to one-half pound. However, the numbers of refrigeration loops produced annually is very large. The estimated 1987 worldwide production of refrigerators and freezers is 58 million units using 8630 metric tons of refrigerant for the initial charge. Because of the small amount required per unit and the reliability of the systems, the use of CFCs in this category is only about 1 percent of the global use of all CFCs. Only about 10 percent of the refrigeration loops require servicing during their lifetime. Although foams will be discussed in another section, it should be noted that about 4 percent of the global CFC use is in blowing the foam insulation for household refrigerators and freezers. CFC blown foam insulation is a large contributor to energy efficiency (Reference 5).

The search for replacement refrigerants for the refrigerator and freezer industry is complicated in the U.S. by reduced energy consumption requirements under the National Appliance Energy Conservation Act of 1987. Energy consumption standards are specified, based on the volume of the appliance, in kilowatt hours consumed per year effective 1 January 1990, reduced further effective 1 January 1993 (Reference 21). This makes finding acceptable replacements and alternate processes for CFC-12 as a refrigerant and CFC-11 as a foam-blowing agent more challenging. Most of the potential replacements identified to date that meet some of the critical requirements, such as a low, or no, ozone depletion potential, nontoxic and nonflammable, are projected to be less efficient than CFC-12 in the refrigeration cycle.

Initial predictions on the performance of HFC-134a for domestic appliance applications indicated oil miscibility problems and a 5 to 10 percent reduction in efficiency from CFC-12. However, more recent refined modeling and initial testing show that it can be as efficient as CFC-12 with use of ester based synthetic oils, which were found to be compatible with the HFC-134a. The potential of further increased efficiency with optimization of compressors, condensors, evaporators and other components and controls, specifically for HFC-134a, seems to be good. It is estimated that the average retail cost increase using HFC-134a systems will be about \$20 to 30 per unit (Reference 19). The long-term "best choice" for this application will likely take considerable time to evolve.

CFC-12 use for the household refrigerator/freezer category was reported by the USAF for 1989 as 3-metric tons or 0.2 percent of all USAF CFC uses. The specific units in the category were not noted (new appliances already charged, repair of old systems, disposal of unservicable units, etc.). In any case, this does not appear to be a significant problem for the USAF since most, if not all, of the applications are likely to be in the nonessential use category.

## B. CLEANING SOLVENTS

As defined by the DOD (Reference 9), CFC solvent cleaning agents are those used for cleaning of metals, optics, electronics, automotive electric systems, and printed circuit boards. CFC solvent cleaning accounts for 16 percent of the use of CFCs worldwide (Reference 22). CFC-113 is used in the majority of the solvent cleaning applications. Methyl chloroform (also known as 1,1,1-trichloroethane or TCA) and, to a lesser extent in the U.S., carbon tetrachloride are also used for solvent cleaning. Carbon tetrachloride and methyl chloroform were added to the Montreal Protocol list of controlled substances designated as Class I, Group IV and V to be phased out by 2000 and 2005 respectively.

The electronics industry is the largest worldwide user of CFC-113. In 1986, about 45 percent (40,000 metric tons) of the CFC-113 consumption worldwide was for removal of solder flux from printed circuit board assemblies (Reference 23). Removal of fluxes and flux residues after soldering has been considered essential for high quality electronic assemblies to ensure reliable electrical performance and adhesion of conformal coatings and encapsulation compounds. It is estimated that about half of the CFC-113 use in the electronics industry results directly or indirectly from military specifications (Reference 22). Extensive work is underway to qualify non-CFC replacement cleaning agents and alternate processes so that military specifications can be changed to allow use of these new cleaning techniques.

The DOD, Environmental Protection Agency (EPA), and the Institute for Interconnecting and Packaging Electronic Circuits (IPC) formed an Ad Hoc Solvents Working Group in 1988 to evaluate alternatives that reduce the use of CFCs in electronics cleaning. The Working Group has developed a three-phase program to meet its objectives: Phase 1 - Benchmark Testing, Phase 2 - Limited Alternative Cleaning Media Evaluation, and Phase 3 - Alternative Technology Testing.

Phase 1--Benchmark Testing involves using existing nitromethane stabilized CFC-113/methanol azeotrope blends to clean standard printed board assemblies in order to establish baseline cleanliness data with which to compare new processes and cleaning agents. Phase 1 was completed in March 1989 (Reference 24).

Phase 2--Limited Alternative Cleaning Media Evaluation is a duplicate of the Phase 1 effort except for substituting selected alternative cleaning media for comparison with the benchmark results. Some of the first products to have completed Phase 2 testing are Genesolv® 2010 and 2004 from Allied Signal, Inc., MARCLEAN-R from the Martin Marietta Corp., BIOACT EC-7 from Petroferm Inc., and AXAREL 38, KCD 9434, and SMT from Du Pont. Individual reports documenting the results of each agent tested are available. Testing is continuing to qualify other alternative cleaning agents.

Phase 3--Alternative Technology Testing will involve a review of the results of Phases 1 and 2 and modification of the test plan if required. It will also involve a determination of the mixture of fabrication, assembly processes, cleaning materials, and cleaning processes for evaluation and the capability of alternative fluxes, soldering processes, fusing processes, etc., to fulfill cleanliness requirements.

The Industry Cooperative for Ozone Layer Protection (ICOLP) was formed to provide users of ozone-depleting solvents with up-to-date information on alternative processes and technologies as industry begins research programs to phase out the use of these compounds. Members include Northern Telecom, AT&T, General Electric, Motorola, Texas Instruments, Honeywell, Digital Equipment, Ford Electronics, British Aerospace, Compaq, and Boeing. A move is now underway to encourage other large solvent users in Europe, Asia, and elsewhere to join. The EPA and other government agencies are involved in ICOLP through Memoranda of Agreement. Membership categories include (1) user companies, regardless of size, (2) suppliers to the industry, (3) associations, (4) public advocacy groups, and (5) other interested parties. Essentially,

any organization or person interested in ozone-depleting solvent technology transfer is invited to participate.

In carrying out its mission, ICOLP collects and distributes nonproprietary information to solvent users worldwide, cosponsors conferences, and participates in meetings. ICOLP is committed to building an industry specific data base that will contain important information of interest to solvent users. Called OZONET, it is accessible through General Electric's worldwide network via a local telephone call in 750 cities (Reference 25). ICOLP is also producing state-of-the-art manuals on the following subjects:

1. Aqueous and Semiaqueous Alternatives to CFC-113 and Methyl Chloroform
2. Inert Gas Soldering Alternatives to CFC-13 and Methyl Chloroform
3. Low solid Flux and Paste Alternatives to CFC-113 and Methyl Chloroform
4. Riveting Without CFC-113 and Methyl Chloroform
5. CFC-113 and Methyl Chloroform Solvent Containment
6. Precision Cleaning Without CFC-113 and Methyl Chloroform

Peer review drafts of four of the manuals were released in November 1990.

The USAF and DOE have been working over the last few years in a cooperatively funded effort to find replacement solvents, primarily for metal cleaning/degreasing applications. The program consists of three phases. In Phase I, over 250 solvent cleaning products were screened to select those meeting criteria for cleaning and environmental qualities (Reference 26). Five compounds were selected to enter the Phase II small-scale testing (Reference 27). The Phase III, full-scale testing, has been essentially completed with two compounds selected to be incorporated into the Air Force Air Logistic Center aircraft maintenance and overhaul facility cleaning

processes at Tinker AFB, Oklahoma. The final report for Phase III has not yet been completed.

Manufacturing organizations around the world are assessing and developing new and improved solvents and cleaning technologies. As an example, Northern Telecom established one of the most aggressive CFC-based solvent elimination programs in the world with a goal of total elimination of CFCs by 1991. AT&T is exploring terpene cleaning processes and developing new technologies in the area of spray fluxing. Digital Equipment recently developed the Augusta Aqueous Microdroplet Module Cleaning Process, which uses water-based solutions for cleaning boards and electronic modules. Ford Electronics and Motorola are both aggressively pursuing controlled atmosphere soldering and low-solids fluxes and pastes. Texas Instruments is focusing on low-solids fluxes and aqueous washing. Bendix/King has been evaluating Allied Signal Genesolv/Baron-Blakeslee Series 2000 HCFC-based solvent alternatives. In Japan, Seiko-Epson is working on low-solids fluxes, NEC has installed a pilot terpene cleaning process in one of their plants, Matsushita has installed controlled-atmospheric soldering, and Asahi Glass Co., Ltd. is developing two chemical alternatives, HCFC-225ca and 225cb. In Europe, L. M. Ericsson is using low-solids fluxes and controlled-atmosphere soldering, and Siemens has commissioned in-line alcohol cleaning and controlled-atmosphere soldering (Reference 25).

Aqueous cleaners are the least toxic, most environmentally "friendly," and very cost effective. Several systems are readily available at reasonable costs. Changing the production process, such as using alternative solder techniques and/or fluxes and mounting technologies, may help to facilitate the introduction of aqueous cleaning. The introduction of new agitating, rinsing, drying, and recycling/waste reduction equipment makes aqueous cleaning an effective cleaning alternative. Some difficulties with water-based products include poor cleaning action on some types of dirts, corrosion, staining and spotting, and poor penetration or wetting of tightly packed parts. In addition, water-based products require large amounts of energy to evaporate the water. Problems may

arise with disposal of the spent water phase, which may contain lead leached from the solder or other environmentally undesirable contaminants. Exposure to water can damage some sensitive electronic components; particularly vulnerable are any parts not hermetically sealed where water can penetrate and be trapped, such as capacitors and inductor or transformer coils. For these reasons solvents containing water are judged less attractive for some applications.

Effective semiaqueous cleaning systems are being introduced into several facilities (References 26 and 27). Many of these agents and systems present drying, flammability, and VOC problems that have to be solved. When there is a high probability of loss to the environment, terpenes are recommended, provided they are not released as a vapor (VOC). Terpenes are widespread in the environment, thus discharges (other than VOC emissions) would be natural products and environmentally benign provided any contaminants such as metal flux residues have been removed.

Nonaqueous cleaning agents have a long history of successful usage: alcohols, ketones, aliphatic and aromatic hydrocarbons have long been used with good results (References 26 and 27). However, flammability problems are inherent with many of these materials.

Processes using halocarbons facing restrictions (e.g., CFC-113 and methyl chloroform either as pure agents or in blends) are not recommended for introduction into new facilities and production processes. Blends containing HCFCs such as HCFC-123 and HCFC-141b show promise as near-term or interim agents, though they face phaseout between 2020 and 2030 under the Montreal Protocol and 2015 under the CAA 1990. It is also possible that the phaseout schedule may be accelerated by future legislation.

The USAF reported use of 1343.5 metric tons of CFCs in the solvent category for 1989. This made up about 81 percent of all USAF CFC use for 1989. CFC-113 made

up 97 percent of the solvent use, with CFC-12 at 2.5 percent and CFC-11 at 0.5 percent. The solvent end use was further broken down to 68 percent for mechanical systems cleaning and 32 percent for electronic systems cleaning. Since the USAF does not in general manufacture and assemble electronic systems, it is presumed that the solvent amounts reported for electronic cleaning were primarily from government-owned contractor-operated (GOCO) facilities. The same is presumed to also be the case for solvent use for cleaning mechanical systems. The other large users of solvents in the USAF are the major repair depots for aircraft, engines, missiles, avionics and other weapon related systems.

The technology appears to be progressing well for replacement solvents or alternative processes for solvent cleaning to meet or exceed the phaseout schedule for CFCs. There are definite cost impacts whether it is initially from higher tax-added costs for CFCs in the interim or higher capital expenditures for equipment for alternate cleaning processes. Since there are so many cleaning scenarios and variables involved throughout the industry, it is very difficult to predict a cost impact. The requirements for each specific cleaning process have to be identified and an evaluation and selection of alternatives made to meet those requirements. Small-scale validation testing should be done before full commitment to a specific process.

### C. FOAM BLOWING

Foam blowing is defined by the DOD as "CFCs used as blowing agents in the production and installation of insulation foams, and packaging materials" (Reference 9, p. 10). There is a wide variety of types and uses of foam products. The foam structure is basically of two types: open cell and closed cell. Foams can be either flexible or rigid depending on the application. Table 14 shows a breakdown of the basic foam types and their general end uses (Reference 22). CFCs-11, -12, -113, and -114 are all used to some extent in the manufacture of foam plastic products. Major end-use applications include

TABLE 14. TYPES AND MAJOR USES OF CFC-BLOWN FOAMS.

Cell Structure	Type	Plastic	Fraction of 1986 Use, %	Intermediate Form	End Use
Open Cell	Flexible Foam	Polyurethane	23	Slabstock	Furniture cushions, bedding, carpet underlies
				Moulded	Seat cushions, moulded furniture
	Rigid Packing Foam	Polyurethane	7	Poured	Packaging
Closed Cell	Rigid Insulating Foam	Polyurethane	48	Bunstock	Building insulation
				Laminated	Roofing sheaths
				Poured	Refrigeration and building insulation
				Sprayed	Wall and roof insulation
	Polystyrene		7	Boardstock	Building insulation
	Phenolic		1		Building insulation
	Rigid Packaging Foam	Polystyrene	8	Sheet	Stock food trays, carry-out containers, egg cartons
		Polypropylene	6		Cushioning, packaging
	Polyethylene				Protective packaging, flotation devices

building and appliance insulation, cushioning, packaging, floatation devices, and shoe soles.

The foam industry used about 267,000 metric tons or about 25 percent of CFCs worldwide in 1986 (Reference 22). CFCs are used as blowing agents in foam manufacturing because they have suitable boiling points and vapor pressures, have low toxicity, are nonflammable, nonreactive, cost effective, and have a very low thermal conductivity. In insulating foams, the CFCs are retained in the closed cell structure, giving them excellent insulating characteristics (R-value per unit thickness). The tradeoff in using different blowing agents (instead of CFCs) for insulation is that the R-values are likely to be lower resulting in greater loss of energy or requiring the use of a thicker foam layer to achieve the same results.

Alternate processes and replacement agents have been proposed to reduce and eventually eliminate the use of CFCs in the foam industry. The use of water along with CFC-11 can reduce the use of CFC-11 in polyurethane foams up to 30 percent (Reference 28). In addition, HCFC-22, HCFC-123, HCFC-124, HCFC-141b, HFC-134a, methylene chloride, AB Process and Polyol Technology have been proposed as replacement agents or processes for CFCs, either as direct replacements or as blends depending on the application. A number of factors must be considered in determining the acceptability of some of these replacement agents and processes, such as, environmental acceptability, availability in sufficient quantities, adaptability to the process, and possible degradation of resultant product. However, projections have been made that the foam industry could eliminate use of CFCs by 1995 (Reference 28).

The USAF reported use of 11.4 metric tons of CFC-11 in the foam end-use category for 1989. This represents 0.7 percent of the total USAF CFC use for 1989. It is not known what foam uses are included in the amounts reported. It appears that the technology is progressing in the development of replacement blowing agents and alternate processes for the foam product industry to meet or exceed the Montreal

Protocol CFC use reduction and phaseout dates. There may be some penalty in the insulating properties of foams blown with replacement agents, which could result in increased costs because of poorer insulating properties or increased material costs for thicker foams to achieve insulation values equivalent to CFC blown foams.

#### D. HALON FIRE SUPPRESSANTS

Halons are fully halogenated hydrocarbons that exhibit excellent firefighting characteristics. They are electrically nonconductive, dissipate quickly, leave no residue and are very safe for human exposure in the concentrations required for fire extinguishment. This combination of attributes has led to the widespread use of halons for fire protection of computer and electronic equipment facilities, museums, engine spaces on ships and aircraft, ground protection of aircraft, and other general industrial and office high value and critical fire protection applications. The estimated worldwide use of Halons 1211, 1301, and 2402 are shown in Table 15 (Reference 29). Note that for 1986 less than 10 percent of halons produced were used for firefighting, about 15 percent of the use was through controllable emissions, and about 75 percent of the halons produced were banked in systems or in reserves. Controllable emissions are emissions of halons as a result of training with portable extinguishers or testing of fixed system installations, unwanted or accidental discharge of fixed systems and portable fire extinguishers and service related emissions from both fixed systems and portables.

It has proven difficult to obtain reliable numbers for halon production. The best estimates are probably the recently reported CEFIC (Conseil Europeen des Federations de L'Industrie Chimique) data shown in Figure 3 (Reference 30). The CEFIC estimates do not include data for Halon 2402, whose 1986 world production has been estimated as 1000 metric tons (Reference 29). Halon 2402 is used mostly in Eastern Europe and the USSR, and less so in the US, for fire suppression. For that reason, the following discussions will only include Halons 1211 and 1301.

TABLE 15. 1986 ESTIMATED WORLDWIDE CONSUMPTION OF HALONS.  
(METRIC TONS).

Portion of Production	Halon				Fraction of Total, %
	1211	1301	2402	Total	
Banked	7,000	11,200	850	19,050	76.2
Controllable Emissions					
Test/Training	1,100	840	20	1,960	7.8
Unwanted Use/Discharge	300	140	10	450	1.8
Service Losses	900	420	20	1,340	5.4
Fires	700	1,400	100	2,200	8.8
Total	10,000	14,000	1,000	25,000	
Percent of Total	40	56	4	100	

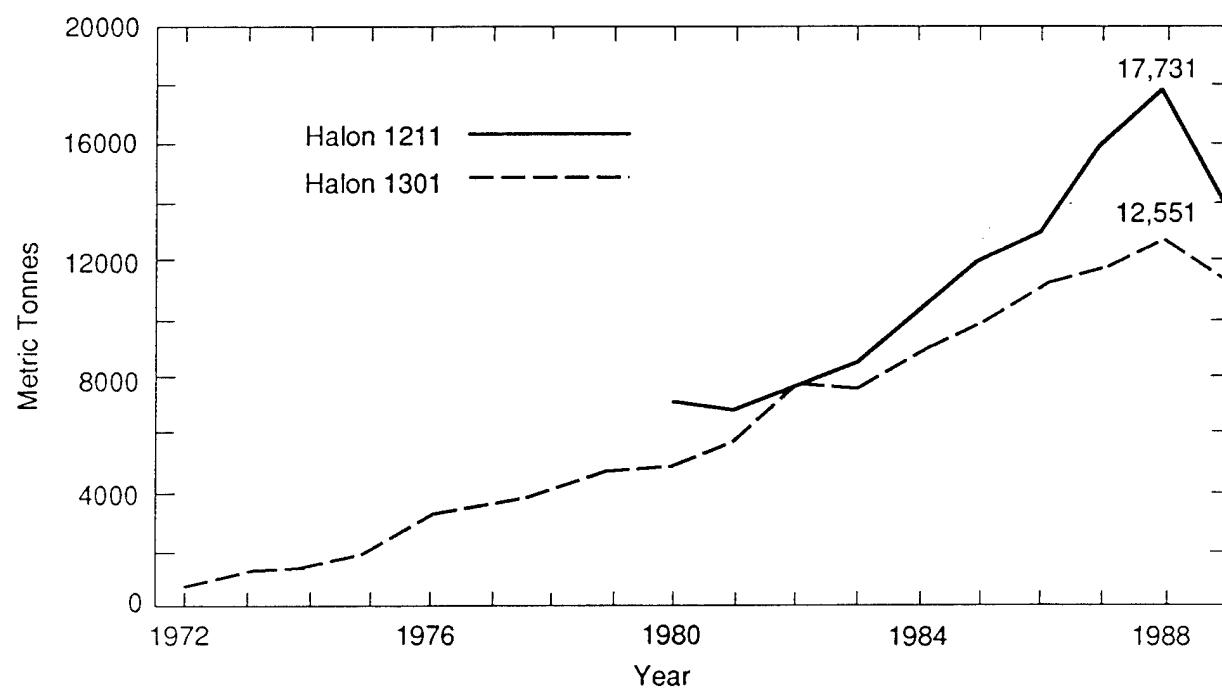


Figure 3. Estimated World Halon Production.

The production of both Halon 1211 and Halon 1301 peaked in 1988 at approximately 17,731 metric tons of 1211 and 12,551 metric tons of 1301 and has been declining since that time. Based on 1986 estimates, approximately one-third of this market was North America, one-third was Western Europe, and one-third was other sectors (Reference 6).

Figure 4, which gives the estimated breakdown in world halon use in 1986, shows that 70 percent of Halon 1301 and 80 percent of Halon 1211 was banked. Note that these estimates, which come from the UNEP Technical Options report (Reference 29), are considerably larger than the CEFIC estimates of the fraction of material banked (Reference 30).

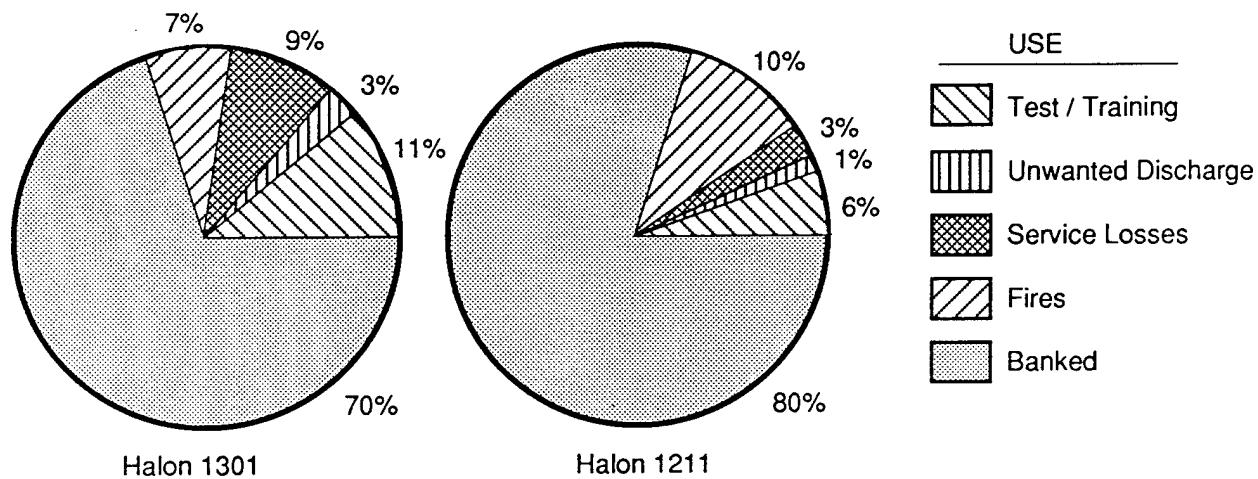


Figure 4. Halon Usage Based on 1986 Levels.

## 1. Present Replacement Technology

Research and development programs for halon replacements have been established by a number of CFC and halon producers. Most of the candidates reported to date are similar to the candidate CFC replacements in that they contain no chlorine or bromine and/or they are designed to have reduced atmospheric lifetimes. Reduced lifetimes for chemicals can be obtained by molecular modification to increase the rates of removal from the atmosphere through various sink mechanisms. For example, addition of hydrogen atoms or carbon-to-carbon double bonds increases the rate of reaction with tropospheric hydroxyl radicals. Adding chromophores (light-absorbing groups) such as carbon-to-iodine bonds or geminal dibromides (two bromine atoms on the same carbon atom) increases the rate of photolysis. Increasing the polarity of the molecule increases its solubility in atmospheric water droplets and increases the rate of co-precipitation with water ("rain-out"). Although a number of candidates have been announced, all of them require some tradeoffs in effectiveness, ODP, and/or toxicity. Moreover, many of these candidates have not been thoroughly tested and may not be applicable or adequate for all fire threat scenarios. Finally, some of the announced candidates, in particular the hydrochlorofluorocarbons, are or will probably be regulated under the Montreal Protocol and will provide only an interim solution.

Seven specific candidate halon replacements have been announced by industry (Table 16). The prefixes "HCFC," "HFC," and "HBFC" denote, respectively, "hydrochlorofluorocarbon," "hydrofluorocarbon," and "hydrobromofluorocarbon."

Table 17 gives the extinguishment concentrations, ODPs, and LC<sub>50</sub> or ALC values for the announced candidates. The data given are those contained in the industrial announcements. Data for the existing halons are also included. The LC<sub>50</sub> is the concentration lethal to 50 percent of a population, and the ALC is the approximate lethal concentration. These are acute toxicities (usually determined in 4-hour rat

TABLE 16. INDUSTRY-ANNOUNCED HALON REPLACEMENT CANDIDATES.

Candidate	Formula	Application
HCFC-123	$\text{CF}_3\text{CHCl}_2$	Streaming
HFC-125	$\text{CF}_3\text{CHF}_2$	Total Flood
HFC-23	$\text{CHF}_3$	Total Flood/Pressure
HBFC-22B1	$\text{CHF}_2\text{Br}$	Streaming/Total Flood
HBFC-124B1	$\text{CF}_3\text{CHBrF}$	Streaming
CFC-11/-114/HCFC-22 Blends	$\text{CCl}_3\text{F}/\text{CClF}_2\text{CClF}_2\text{CHClF}_2$	Streaming/Total Flood

studies) and do not necessarily reflect the many other toxicity issues that may need to be assessed. The ODPs for all materials except 124B1 have been determined from rigorous atmospheric model calculations. The ODPs given for Halons 1301 and 1211 are taken as those cited in the Montreal Protocol, rather than the recently obtained values of 14.1 and 2.4 from Lawrence Livermore National Laboratory. The fire extinguishment concentrations in this table are the agent concentrations in air required to extinguish a heptane fire. Extinguishment concentrations depend on the specific apparatus and methodology used; however, values determined by different organizations are likely to agree within 1 percent (absolute). Fire extinguishment concentrations are good indicators of efficiency in total-flood fire extinguishment applications, but they may not reflect well on agent performance in streaming applications, in explosion suppression, or in inertion.

The HCFC-123, HFC-125, and HFC-23 candidates are or will be produced as CFC replacements or as byproducts, and are, therefore, expected to be readily available in bulk. HCFC-123 is being commercialized as a streaming agent replacement

TABLE 17. COMPARISON OF INDUSTRY CANDIDATES AND HALONS.

Agent	Ext Conc, %	ODP	Toxicity Rat 4 Hr, %
Halon 1301	3.5	10	ALC or LC <sub>50</sub> 40-80 <sup>1</sup>
Halon 1211	3.8	3	LC <sub>50</sub> 13.1 <sup>2</sup>
HCFC-123	7.1	0.02	LC <sub>50</sub> 3.2 <sup>3</sup>
HFC-125	10.1	0	LC <sub>50</sub> 70 <sup>4</sup>
HFC-23	14.0	0	ALC >>65 <sup>1</sup>
HBFC-22B1	4.0	1.1	LC <sub>50</sub> 10.8 <sup>2</sup>
HBFC-124B1	3.6	0.4 <sup>5</sup>	--
CFC/HCFC blends	--	0.5-0.8 <sup>6</sup>	LC <sub>50</sub> 30-37 <sup>6,7</sup>

<sup>1</sup>Du Pont Haskell Laboratory of Toxicology.

<sup>2</sup>Halon News, Great Lakes Chemical.

<sup>3</sup>PAFTT

<sup>4</sup>Vogelsberg, F.A., 1990, personal communication to J. A. Cotnevo, OTS/EPA.

<sup>5</sup>Estimated.

<sup>6</sup>The first number is for a streaming blend, the second for a total-flood blend.

<sup>7</sup>Calculated values based on measured values of the constituents of the blends.

for Halon 1211, and the two HFC agents are being considered as Halon 1301 replacements in total-flood systems. HFC-23 has also been suggested for pressurization of extinguishers for streaming agents. A large number of toxicity studies have been completed or are in progress on these HCFC and HFC candidates, and they are known to have very low or zero ODPs; however, they have decreased fire suppression capabilities compared to the existing halons. The relatively high acute toxicity of HCFC-123 may require a risk assessment before consideration for use, particularly in enclosed areas with unprotected personnel present. Alternatively, early results for this agent are very encouraging for most other toxicity issues. The two HFC agents, HFC-125 and HFC-23, have low acute toxicities. Owing to the decrease in efficiency of these HFC candidates, a considerably increased storage volume (compared to that required for Halon 1301) would be needed in any fire protection system.

HBFC-22B1, a bromine-containing compound, now available in relatively large amounts, is being commercialized for both total-flood and streaming applications. At present, this material is not being marketed for use where human exposure is possible. Full toxicity testing to the chronic stage, if required, will probably take several years. HBFC-22B1 has a rather high ODP; however, the relatively low acute toxicity and the excellent fire extinguishment characteristics make HBFC-22B1 otherwise attractive.

HBFC-124B1, a streaming agent with excellent fire extinguishment characteristics, is still very much in the experimental stage. No quantitative toxicological data have been reported; however, industry sources state that early toxicological results look good. Because the estimated ODP for this chemical is above the U.S. Clean Air Act regulatory limits for ozone-depleting materials (an indication of possible regulatory problems in other nations), there are now no plans to make a capital investment in production of this material until such time as the ODP issue becomes clearer.

Two different CFC blends, one for streaming and the other for total flood, are now being marketed. These fully halogenated chlorofluorocarbons have significant

fire-extinguishing capabilities; however, it is difficult to obtain accurate cup burner flame extinguishment concentrations with blends. These blends contain CFCs that have well-defined, low toxicities. Since CFCs have lower ODPs than do the present halon fire-extinguishing agents, substitution of CFCs for halons in selected fire protection applications could reduce the threat to the ozone layer. On the other hand, these materials are regulated under the Montreal Protocol and are in a different category from the halons, which combined, make substitution a highly sensitive issue and unlikely to be widely supported. Certainly, such substitutions could not be regarded as a long-term solution.

Initial commercial announcements of other materials, whose formulas have not been disclosed, have been made.

Nonindustrial development projects are also underway. The Halon Alternatives Research Corporation (HARC) has been established in the United States to encourage and facilitate research and development activities. This Consortium is a group of government and industry leaders who are supporting cooperative efforts for information exchange and complementary research programs. These efforts are intended to support the scientific basis for development and commercialization of clean, safe, and reliable fire extinguishing agents.

Other nonindustrial organizations within the United States that have been or are now involved in research on halon replacements include the following: Center for Global Environmental Technologies at The University of New Mexico; Department of Chemistry at the University of Tennessee; National Institutes of Standards and Technology; the Naval Research Laboratory in Washington, DC. Much work is now being sponsored within the United States by the U.S. military, the U.S. Environmental Protection Agency's Air and Energy Research Laboratory at Research Triangle Park, North Carolina, and the Federal Aviation Authority.

## 2. Future Replacements

Owing to tradeoffs in effectiveness, toxicity, and/or ODP with the announced candidates, the search for replacement fire-extinguishing agents is continuing. A halon replacement must have four characteristics to be considered: a low or zero ODP; an acceptable toxicity; cleanliness and volatility (the primary reasons for using halons in most applications); and good effectiveness for fire/explosion protection. It is relatively easy to find candidate replacements that meet any three of these criteria; however, to date, no agent that satisfactorily meets all four criteria has been identified. While it is likely that better candidates will be found, it will prove difficult to find low-ODP replacements having a toxicity and effectiveness equal to those of the present halons.

Under sponsorship of the USAF Engineering and Services Laboratory, a program has been established to develop Halon 1211 (streaming agent) alternatives for both firefighter training and general-purpose use (References 31 through 39). This effort has identified several candidates that have decreased ODPs and acceptable extinguishment characteristics. Some materials are now undergoing field-scale testing.

Because of their effectiveness, cleanliness, and good dimensionality, halocarbons have been targeted in the halon alternatives program (Reference 40). Hydrogen-substitution provides decreased ozone-depleting (ODP) and global warming potentials (GWP); fluorine substitution decreases the probability of hepatotoxicity (liver damage). Thus, emphasis has been placed on halocarbons containing both hydrogen and fluorine. An exception to this is the consideration of perfluorocarbons, which contain no hydrogen atoms. These compounds have generally low toxicities and zero ODPs, but they may be strong greenhouse gases. Blends look promising for some applications.

In the initial work, a computerized database of 671 haloalkanes containing physical properties toxicity information, estimated ODPs and GWPs, predicted fire

extinguishment characteristics, and other properties was constructed (Reference 41).

This computerized database is being used to separate chemicals into three groups according to toxicity and time availability.

Field testing includes Class B fires of up to 150 ft<sup>2</sup>. The testing indicates that some materials and blends approach Halon 1211 in fire extinguishment capability. Although testing at all scales is continuing, promising candidates are undergoing further evaluation to optimize extinguisher delivery pressures, fill ratios, and nozzle design. A draft performance specification for a Halon 1211 alternative for firefighter training was produced; however, material compatibility testing, personnel exposure studies, additional combustion product analyses, and other evaluations will be needed before fielding.

Work to date indicates that HCFCs, HFCs, perfluorocarbons, and their blends will provide acceptable clean alternative agents to replace Halon 1211 in firefighter training, and, when optimized, may provide at least first-generation alternative general-purpose streaming agents. Although this work is directed toward streaming agents (Halon 1211 alternatives), some materials that should be given careful consideration for total-flood agents (Halon 1301 alternatives) have been identified.

### 3. Halon Alternatives

In many cases, new fire/explosion protection approaches permit reduction or elimination of halons through the use of more conventional fire extinguishing agents, such as carbon dioxide, water, foam, and dry chemicals. It is virtually assured that these alternatives will lead to a shrinking production of halon replacement chemicals. Moreover, the longer it takes to develop acceptable chemicals, the smaller the production will become. It is not unreasonable to expect production of halon replacements to be only 10 percent that of the present production in terms of kilograms produced. Cost of replacements is likely to be much larger since the chemicals will probably be more expensive. Moreover, since halon replacements may be used primarily

in specialized, critical applications, where equipment costs are large, the costs for replacement equipment and systems could be substantial.

The halon alternatives are not without drawbacks. Carbon dioxide is the only clean, gaseous nonhalon agent. Unfortunately, it requires an extinguishment concentration well above the lethal concentration and cannot be used in normally occupied spaces as a total-flood agent, unless steps are taken to ensure egress of all personnel prior to discharge.

The remaining halon alternatives -- water, foam, and dry chemicals -- can cause secondary fire losses: damage due to the agent only. Alternative technologies are needed to permit their use without unacceptable secondary losses. For example, water-resistant computers and redundant computer facilities allow use of water sprays for computer room fire protection without unacceptable losses from computer damage or downtime. More reliable detectors facilitate safe egress of personnel from areas protected by carbon dioxide.

In some cases, alternative agents cannot be used even when damage is acceptable; for example, only halocarbons are likely to be effective for inerting of explosive or flammable atmospheres. Even here, however, alternative technologies will help reduce halon dependence. Localized halon application systems and fire-resistant construction can greatly reduce the amount of halon required. Better and more comprehensive risk management plans will also help to decrease halon requirements.

Alternative approaches to limit emissions of halons and to preserve existing stocks are being developed. Some approaches in this area are the following: improved dispensing hardware, more reliable detectors, recovery and recycling, and bank management. These approaches are necessary to maintain stocks for future "essential" uses of halons.

The technologies for halon replacements do not appear to be as developed as those for CFC replacements in applications such as refrigeration and air-conditioning, foam blowing, and cleaning solvents. Alternatives to halons for fire protection are practical in many areas where halons are now used. There are some applications, however, where a halon or halon-like replacement is essential for explosion and/or fire suppression where personnel must be present or high value equipment such as aircraft, must be protected, and where redesigning and changing current systems is extremely costly and impractical.

The USAF estimated use of 416 metric tons of halons for 1989 (Table 7), which represents about one-third of the DOD total use. The breakout of USAF 1989 reported use between Halon 1211 and 1301 was 310 and 106 metric tons respectively (Table 10). End uses reported for Halons 1211 and 1301 are shown in Table 9). The majority of the Halon 1211 use (64 percent) was in portable extinguishers for protection against flammable liquid fires, while 93 percent of the Halon 1301 use was for electrical/electronic equipment protection. Note that USAF reported 76 percent of halon uses in the mission-critical category with the remaining 24 percent in the essential category. None of the services reported any halon uses in the nonessential category (Table 7).

## E. OTHER USES OF CRFs

### 1. Aerosols

The use of CFCs in aerosol products, primarily as a propellant but also as a solvent and as the active ingredient in the product, accounted for about 27 percent of the total use of controlled CFCs worldwide in 1986 (Reference 22). In the mid-1970s the use of CFC-11 and -12 in aerosols accounted for about 60 percent of the use of these chemicals worldwide. In 1978, the U.S. banned the use of fully halogenated CFCs as aerosol propellants for uses considered "nonessential." Exempted or essential uses were

allowed for reasons of safety, health, or national security. Familiar products falling into the exempted category were electronic de-dusters, alarm and warning horns, flying insect sprays for food areas, metered dose inhalant drugs such as bronchodilators, and medical skin chillers (Reference 42).

At the time of the 1978 transition, there were no nonflammable liquid propellant replacements for CFCs that were toxicologically approved and available for use. Today the situation has changed with the availability of HCFC-22 and blends of HCFC-22/142b and upcoming availability of HFC-134a, HCFC-123, HCFC-141b, and HCFC-124. One product that will require a long period of transition is the metered dose inhalant drugs, because of the period of time required (often 5 years) by the U.S. Food and Drug Administration to approve a new drug application (Reference 42).

The USAF did not report CFC aerosol use as a separate end-use category. However, the CFC aerosol phaseout and transition is not expected to be a problem area. Several companies that produce electronic dedusters and cold testers have already switched to non-CFC aerosols such as HCFC-22. The aerosol use transition likely to take the longest is in the medical applications.

## 2. Sterilants

Ethylene oxide is widely used in the medical field by equipment manufacturers and hospitals for gas sterilization of medical equipment and devices. It has the ability to penetrate packaging materials and is particularly useful for sterilizing heat sensitive products that could otherwise be steam sterilized. However, ethylene oxide is toxic, mutagenic, a suspected carcinogen, flammable, and explosive and thus requires stringent safety precautions. To reduce the flammability and explosive risks, it is usually diluted with CFC-12 to a mixture of 12 percent ethylene oxide and 88 percent CFC-12 by weight. This mixture is commonly known as "12/88" (Reference 22).

The total use of CFC-12 worldwide for sterilization is estimated at 20,000 to 25,000 metric tons annually. U.S. use accounts for about half of that with 30-40 percent attributed to hospitals that use the "12/88" mixture (Reference 22).

The USAF estimated the use of 13 metric tons of CFC-12 in 1989 in the sterilization category (Table 8), which amounts to only about 0.8 percent of the total USAF use of CFCs for 1989. The sterilization category as defined by the DOD included "CFC-12 as used to dilute ethylene oxide in sterilization processes to reduce flammability and explosion risks" (Reference 9). It is presumed that the use in this category reported by the USAF was primarily, if not exclusively, for hospital sterilization. Alternatives to CFC-12 use already exist in sterilization processes. Another diluent used with ethylene oxide is carbon dioxide. One commercially available nonflammable mixture is 10 percent ethylene oxide and 90 percent carbon dioxide, known as "10/90." However, this mixture requires equipment capable of much higher operating pressure than required by "12/88." It is estimated that about half of the "12/88" equipment in the U.S. is not certified to operate with the high pressures of "10/90." These higher pressures would require the purchase of new equipment. Steam sterilization is a viable alternative for products that can tolerate temperatures above 121 °C. Some equipment manufacturers are investigating the use of mixtures of HCFCs with ethylene oxide as possible drop-in replacements for "12/88" equipment. It appears that alternate technologies are either available or emerging to allow elimination of CFC-12 in sterilization well before the phaseout date of 2000.

### 3. Other

The other CFCs reported by the USAF in this category for 1989 were 0.5 metric tons of CFC-114, 0.2 metric tons of R-500, and 0.05 metric tons of R-502 (Table 9). CFC-114 is used in the LANTIRN pod Environmental Control Unit. R-500 and R-502 are typically used for low-temperature refrigeration.

## SECTION V

### MISSION IMPACT OF CFC AND HALON PHASEOUTS

The previous section discussed the state of current technologies for CFC and halon replacement and alternative technologies and the availability of those technologies against the phaseout dates of the Montreal Protocol and CAA 1990. This section will address specific USAF mission impacts of the phaseouts of CFCs and halons, taking into account replacement and alternative technologies.

The DOD survey and report of the use of CFCs and halons (Reference 9) included a breakout by mission critical, essential, and nonessential categories by compound (Tables 11 and 12) but did not report specific mission-critical end uses. In January 1990, HQ USAF/LE requested a survey be done by Air Force Systems Command (AFSC) and Air Force Logistics Command (AFLC) of the full-scale development and technology base programs for specific mission-critical uses of CFCs and halons (Reference 43). The AFSC and AFLC responses (References 44 and 45) were used to identify specific mission-critical end uses where technology gaps may exist when compared to the CFC and halon phaseout schedules and the technology assessments in Section IV.

#### A. REFRIGERANTS

The refrigerants category of CFC uses included three subcategories: large refrigeration and air-conditioning, mobile air-conditioning, and household refrigeration. These in turn include cold storage, retail food refrigeration, industrial process refrigeration, building and industrial process chillers, cooling in motor vehicles, home refrigerators and freezers, and other small household appliances such as dehumidifiers and ice machines. Traditional uses in these categories would not be classified as mission critical. However, refrigerant uses that have a direct impact on combat mission assets would be classified as mission critical. Although CFC replacement refrigerant

technologies are progressing well, it is probably impractical in some weapon systems applications to make the switch from CFCs because of the extremely high retrofit equipment costs required to achieve the necessary high reliabilities.

Aircraft environmental control is accomplished by different systems depending on whether the aircraft is operating or parked on the ground. Environmental control for most military aircraft while parked is accomplished with a portable air-conditioning cart connected to the aircraft. As CFC replacements and hardware are available, these carts can be replaced. Aircraft airborne environmental control has traditionally been achieved with air cycle (where air is used as the refrigerant) rather than vapor cycle refrigeration. Recent trends in aircraft design have been to use vapor cycle refrigeration with CFCs because of the higher coefficient of performance. Currently, the RC-135 V/U, EC-18B ARIA, E-8A JOINT STARS, C-12, and T1A aircraft and the PAVETACK and LANTIRN weapons systems use either CFC-12 or CFC-114 as refrigerants (Reference 33).

Newer aircraft in the design/development stages, such as Air Force One Replacement, Advanced Tactical Fighter, B-1, B-2, C-17, and C-29, are scheduled to use CFC vapor cycle refrigeration systems for environmental control. Some or all of these newer aircraft could possibly be designed to use CFC replacements if the technology of CFC replacements and associated hardware advances soon enough. For the existing aircraft and weapons using CFCs, it does not appear at this time that a "drop-in" CFC refrigerant replacement (one that performs essentially the same as a CFC and does not require hardware changes) will be forthcoming. Those resources currently have no options for exceptions to the production phaseouts under the CAA 1990, except those using CFC-114. The CAA 1990 provisions for exceptions to the phaseout dates for reasons of aviation safety only apply to Halons 1211, 1301, and 2402. The CAA 1990 provision for a presidential waiver in the interest of national security only applies to CFC-114 and Halons 1211, 1301, and 2402 (Table 5).

Existing systems using CFCs that are mission-critical resources will have to rely on maintaining a bank of the needed CFC sufficient to last the lifetime of the system. Recovery and recycling of CFCs plays a very important part in reducing CFC emissions and maintaining a bank adequate for future needs.

Some other specialized applications of CFC refrigerants in the mission-critical category are on space launch vehicles and ballistic missile systems. The TITAN IV Guidance Control Unit uses R-502 for cooling. R-502 is a blend of 49 weight percent of HCFC-22 and 51 weight percent of CFC-115. HCFC-22 production is being phased out by 2015 and CFC-115 by 2000. The Peacekeeper ballistic missile Guidance and Control Conditioning Units use CFC-12 refrigerant. Redesign of these existing systems for CFC replacements would be cost prohibitive and therefore maintaining a proper bank of CFCs is essential to support the requirements throughout the life of the systems.

## B. CLEANING SOLVENTS

There is a heavy dependence on CFC cleaning solvents for electronic, metal, and precision cleaning by the USAF and its contractors. In 1989, 1343.5 metric tons or 81 percent of all USAF CFC use was reported in the solvent category (Table 8). The USAF reported all of the CFC-113 use for 1989 as cleaning solvents and in the mission critical category. The use of CFC-113 made up 97 percent of the USAF reported solvent usage (Tables 8 and 11).

As discussed in Section IV B, the technologies for alternatives to CFC cleaning solvents in general are progressing very well, although considerable effort and expense will be required to make the transitions. The most difficult transitions will be qualifying alternate cleaning solvents or processes for use in weapon systems electronics and precision cleaning applications where very high reliabilities are required over long system lifetimes. Modifying over 300 MILSPECs and MILSTDs that directly or indirectly specify use of CFC solvent cleaning will also be an arduous but necessary task. There do

not appear to be any technology gaps wherein alternative cleaning solvents or processes cannot be adapted or developed prior to the scheduled phaseouts of CFC solvents. However, an aggressive program must be undertaken by users to find the optimum solution for each specific end-use application. This will likely be a costly effort for many applications.

### C. FOAM BLOWING

No CFC foam-blowing uses were specifically identified by the USAF in the mission-critical category by References 9, 33, or 34. Furthermore, no cases were found where the USAF performs foam blowing operations. The USAF is therefore assumed to be only a consumer of finished foam products procured from the manufacturing industry. The phaseout of CFC foam-blowing compounds should not cause a direct impact on USAF missions since alternative technologies are progressing well. There could be a net increase in energy use due to poorer insulating properties of non-CFC blown foam insulation, or increased costs for added thickness to achieve the same insulation.

### D. HALON FIRE SUPPRESSANTS

The USAF reported 315.8 metric tons (76 percent) of 1989 halon uses as mission critical (Table 12). The breakout of the mission critical uses between Halons 1211 and 1301 was not reported; however, the total halon use reported by the USAF for 1989 was a ratio of about 3:1 for Halons 1211 to 1301 (310 and 106 metric tons respectively) (Table 10). Halon 1211 uses are predominantly in portable extinguishers for streaming applications while the Halon 1301 applications are predominantly total flooding fixed systems (Reference 46).

## 1. Halon 1211 Streaming Agent

Mission-critical uses of Halon 1211 reported by the USAF range from 5-pound hand-held extinguishers used in a variety of locations to 500-pound units on Crash Fire Rescue (CFR) vehicles (References 44 and 45). USAF passenger, cargo, and larger combat aircraft use portable Halon 1211 extinguishers to combat fires inside the aircraft in spaces accessible to personnel during flight operations where efficient and safe fire suppression is essential. Halon 1211 is also used in 150-pound wheeled units on flightlines and in hangars for protection of aircraft while parked, in addition to the 500-pound units on CFR vehicles for flightline emergencies. Halon 1211 portable extinguishers are used extensively to protect high-value weapon systems equipment and facilities worldwide. A few examples are aircraft simulators, missile and satellite hardware, assembly and launch facilities, and early warning radars.

Halon 1211 portables have also been used extensively for protection of office and similar facilities but a recent USAF policy change only allows purchase of Halon 1211 portable extinguishers for aircraft and aircraft support applications (Reference 9). The USAF estimated that 70 percent of USAF halon emissions in 1986 were Halon 1211 used for firefighter training purposes. The USAF has now stopped all use of halon for firefighter training.

It appears that a replacement streaming agent will be available to meet the Halon 1211 phaseout date of 2000. It may not be a "drop-in" replacement and will likely require some hardware changes on existing extinguishers for material compatibility and amount of agent required. The replacement agent could be more expensive than 1211 at first but with the tax added to 1211 as phaseout approaches, the replacement will ultimately be cheaper. A thorough review of the USAF mission-critical classification of Halon 1211 uses will no doubt reduce the requirements for the replacement agent considerably. In fact, diverting Halon 1211 from nonessential uses to a mission-critical applications bank could extend availability for some time.

## 2. Halon 1301 Total-Flood Agent

USAF mission-critical uses of Halon 1301 as a total-flood agent fall generally into two categories. The first is fire protection of aircraft engine nacelles and electronic equipment spaces with some use for explosion suppression of aircraft dry bays and fuel tanks. This type is characterized by small containers or bottles and relatively small amounts of halon. The second is fire protection of computer and electronic equipment rooms of weapon systems and other essential facilities. This type is characterized by large bottles and large quantities of Halon 1301 because of the large volume to protect. Other mission-critical applications include protection of high-value equipment, particularly where personnel may be present when the halon is dumped, such as aircraft training simulators.

Halon 1301 total-flood systems have been used extensively in the past to protect all types of USAF computer and electronic equipment facilities. Because of the concern about stratospheric ozone depletion from halons, this practice was essentially eliminated by USAF policy issued in June 1989 (Reference 46). The policy directed use of means other than halon for fire protection of all new or remodeled electronic equipment facilities. An exception was made for some mission-critical electronic facilities but required approval of a waiver by HQ USAF.

Finding a replacement total-flood agent(s) for Halon 1301 appears to be the most difficult challenge in eliminating CFCs and halon use. In fact, it is likely that two or more agents may have to be used to replace Halon 1301, depending on the application. As an example, a replacement agent that is as efficient as Halon 1301 but more toxic could be used where risk of exposure to personnel is minimal and size and weight of the system are critical, such as in aircraft engine nacelles. Another replacement that is nontoxic but not as efficient as Halon 1301 could be used where size and weight are not critical, such as in electronic equipment rooms. Alternative fire protection means other than Halon 1301 total-flood systems will likely have to be the

choice for most applications where, in the past, 1301 was the easy choice. Some of these alternatives are improved detection systems, more fire resistive facilities, more fire resistive and low smoke producing electronic components, cable insulation, furnishings and interior finish. Other alternative approaches for mission-critical systems are minimizing single point failure modes, use of back-up or redundant facilities and adequate post-fire recovery contingency plans.

It is almost certain that a "drop-in" replacement for Halon 1301 will not be available by the phaseout date of 2000, and such an agent may never be found. It also is not certain at this point that a replacement agent will be available by 2000 for mission-critical applications, such as aircraft engine nacelles and dry bays, that does not require new storage and dispensing hardware systems. The design, testing, and retrofitting of new flight qualified systems in existing aircraft would be very expensive and impractical. CAA 1990 does have an Aviation Safety exception to production limits on Halon 1301 where no safe and effective substitute is available. Even if adequate substitute(s) were available, the Montreal Protocol and CAA 1990 does not prohibit Halon 1301 from being used; consequently, Halon 1301 from banked reserves could be used in existing systems throughout their lifetime. The importance of establishing an aggressive recovery, recycling, and bank management program will be discussed in a Section VI.

### 3. Other USAF Halon Uses

Halon 1202, while not currently controlled by the Montreal Protocol or CAA 1990, is used to a limited extent by the USAF in mission-critical applications. The C-130 and F-111 aircraft use Halon 1202 in the engine nacelle fire protection systems; the C-141A and B and C-5 aircraft use it in the engine nacelle and Auxiliary Power Unit (APU) fire protection systems (Reference 45). Halon 1202 could be added to the CAA 1990 controlled list because it has an ODP of 0.3. The CAA 1990 has a provision that the Administrator of EPA can add any substance to the production controlled list that has an ODP of 0.2 or greater. However, Halon 1202 should be available for the

foreseeable future since it is used as a feedstock in the production of other chemicals. The production of feedstock chemicals is not limited by CAA 1990. If the use of Halon 1202 as a fire protection agent is added to the limitations of CAA 1990, an Aviation Safety exception would be required to allow its continued use in existing aircraft throughout their lifetimes.

Though used very little in the U.S. as a firefighting agent, Halon 2402 is used by the USAF in a different application. It has been used and was planned for future use as a Thrust Vector Control (TVC) fluid in ballistic missiles. The Halon 2402 is injected into the rocket motor exhaust through injector ports in the motor exit nozzle by commands from the guidance system to produce off-axis or "bending" of the exhaust plume to steer the missile. Halon 2402 was selected because of its high density, low heat of vaporization, high thermal conductivity, stability on long-term storage, and minimal health and safety risks. The NMERI HALOCARBON DATABASE® (Reference 41), which contains data on over 650 candidate CFC and halon replacement chemicals, was searched for potential Halon 2402 replacements with characteristics desirable for a TVC fluid application. This preliminary search identified several compounds that might meet the required parameters. Based on the search, it appears that an acceptable replacement for Halon 2402 in this application can be found; however, considerable effort is still required to go through the final selection and verification process.

#### E. OTHER USES OF CFCs

CFCs discussed in the miscellaneous category in the technology assessment (Section IV), included aerosol products, sterilants, and technical specialty products. The USAF did not report use in any of these categories as mission critical.

The use of small amounts of CFC-114, R-500, and R-502 were reported by the USAF for 1989 and identified as mission critical in References 44 and 45. CFC-114 is used in the LANTIRN weapons guidance package in the Environmental Control Unit

(ECU). Although a replacement for CFC-114 is very likely by its phaseout in 2000, hardware changes are almost certain to be required. An evaluation of the LANTIRN system requirements with the replacement agent will have to be made at that time. If a change to a CFC-114 replacement is not feasible by the year 2000, under CAA 1990, the President may issue a production exception for one year for reasons of national security. Congress must be notified within 30 days with justification and the exception expires after one year and must be renewed again each year. Another method to ensure CFC-114 is available for the LANTIRN weapon system is to recover and recycle existing CFC-114 and maintain a strategic reserve bank large enough to last the lifetime of the weapon system.

Specific end uses of R-500 and R-502 for mission critical applications were not identified specifically in References 44 and 45. Replacements for both R-500 and R-502 as low- and medium-temperature refrigerants by the year 2000 seem assured, although some hardware changes are likely.

## SECTION VI

### RECOVERY/RECYCLING/RECLAMATION AND BANK MANAGEMENT

The reduced production and phaseout of CFCs and halons under the Montreal Protocol and CAA 1990 and the desire to reduce emissions of CFCs and halons to an absolute minimum make recovery and recycling essential parts of the solution to the stratospheric ozone depletion problem. Preserving those existing CFCs and halons in banks or reserves to meet critical future requirements necessitates accurate projection of future needs and establishment of a bank management program.

#### A. RECOVERY/RECYCLING/RECLAMATION

The terms "recovery, recycling, and reclamation" could have a variety of meanings depending on the readers' interpretations. The Air-Conditioning and Refrigeration Institute (ARI) has defined these terms to standardize their use in the industry. Those definitions will be used in this report and are as follows:

1. Recovery: To remove refrigerant (halocarbon) in any condition from a system and store it in an external container without necessarily testing or processing it in any way.
2. Recycle: To reduce contaminants used in refrigerant (halocarbon) by oil separation and single or multiple passes through devices that reduce moisture, acidity, and particulate matter, such as replaceable core filter-driers. This term usually applies to procedures implemented at the field job site or at a local service shop.
3. Reclaim: To reprocess refrigerant (halocarbon) to new product specifications, by means which may include distillation. Chemical analysis of the refrigerant will be required to determine that appropriate product specifications are met. This term usually implies the use of processes or procedures available only at a reprocessing or manufacturing facility.

The generic processes of recovery/recycling/reclamation will be referred to by the abbreviation R/R/R.

Until recently, R/R/R of CFCs and halons was not standard practice, particularly with CFCs, because they were relatively inexpensive to replace with new pure agents compared to the cost for recovering and cleaning the CFCs for reuse. Halon recovery was practiced more than CFC recovery because of the higher cost of halons and the low probability of contamination. R/R/R requirements differ for CFC refrigerants, halons, and other CFC applications, so they will be discussed separately.

## 1. Refrigerants

In the past refrigerants were usually released into the atmosphere when equipment was installed, tested, serviced, and repaired. Significant reductions in CFC emissions can be realized by recovering the CFCs and recycling or reclaiming them for reuse. Of course, the added benefit of recovery is increasing the bank of CFC resources so that they will be available after production phaseouts to extend the useful life times of existing mission-critical equipment. The process of simply removing the refrigerant from a system is called recovery. Recovered CFCs usually have some level of contamination, which could be particulates, oils, moisture, acids, and noncondensable gases. The level of contamination of the refrigerant will depend on what it was removed from and why it was removed. If it was removed for periodic servicing of the equipment or repair of a leak, the contamination level could be fairly low. If the refrigerant was removed from a hermetically sealed system that experienced a motor burnout, the level of contamination could be quite high. In any case, the refrigerant must go through some process to remove the contaminants prior to reuse. In keeping with the above definitions, if it is cleaned by processing it through equipment on site or in a local shop, that process is called recycling. If it is recovered and collected in bulk, then shipped to a large reprocessing or manufacturing facility and reprocessed to meet new refrigerant specifications, the process is called reclamation. Because verification of refrigerant

purity requires a relatively expensive laboratory analysis, it is not practical to measure purity in the field on small quantities of recovered and recycled refrigerant.

For the Mobile Air-Conditioning (MAC) segment, several automotive industry professional organizations, in conjunction with the EPA, developed standards on recovery and recycling of refrigerants from MACs. These standards were published by the Society of Automotive Engineers (SAE). SAE J 1989 and SAE J 1990 provide recommended practice and service guidelines for technicians repairing MACs and equipment specifications for CFC-12 R/R/R systems (References 47 and 48). SAE J 1991 establishes minimum purity levels for CFC-12 removed from MACs before reuse in the same or similar systems (Reference 49). Underwriters Laboratories (UL) then developed a safety standard (UL 1963) for CFC-12 MAC R/R/R equipment (Reference 50). UL 1963 is used to evaluate R/R/R equipment for adequacy in recovering and recycling CFC-12 from MACs. A standard contaminated CFC-12 sample, a high-moisture contaminated sample, and a high-oil contaminated sample are defined. In order to be certified, R/R/R equipment must then recycle and clean up the contaminated CFC-12 samples to achieve the purity level established in SAE J 1991.

Industry is responding to the desire to recover and recycle CFCs and the CAA 1990 mandated recovery and recycling requirements in the future (Section II, C, 3). Another incentive to recover and recycle CFCs and halons is the excise tax that applies only to new production chemicals. Over 30 companies in the U.S. and Canada now have CFC recovery and recycling machines on the market. Since MACs are the first to require recovery and recycling under CAA 1990, most of the machines are designed primarily for CFC-12, although many will also handle HCFC-22, R-500, and R-502. Many of the models have now been certified to UL 1963 for CFC-12. A more detailed coverage of R/R/R issues and a market survey of available equipment are included in Reference 51.

Some of the major CFC manufacturers are now accepting recovered CFCs which they reclaim by reprocessing. Some other service companies also recover and reprocess CFCs for resale. The CFC reclaimers reprocess them in bulk and then test and certify that they meet the purity specifications of ARI Standard 700-88 (Reference 52), which is the specification for virgin CFCs.

The stationary refrigeration and air-conditioning industry has been working on standards and requirements for R/R/R of CFCs, similar to those developed for MACs. Refrigerants recovered from stationary systems could potentially be much more contaminated than those recovered from MACs, particularly from hermetic systems that experienced a motor burnout. An ARI committee has been working for some time on a guideline or standard. Since no EPA requirements have been set, it will be a voluntary guideline to certify whether R/R/R equipment meets manufacturers' claims for performance. This guideline will require refrigerants to be cleaned to a purity to meet ARI Standard 700-88.

The EPA must promulgate regulations by 1 January 1992 that control use and disposal of CFCs during service, repair or disposal of appliances and industrial process refrigeration. These regulations will take effect 1 July 1992. Five years after enactment of CAA 1990, regulations must be in place to control emissions of Class I and II substances for all other stationary refrigeration and air-conditioning systems (Reference 4).

## 2. Cleaning Solvents

CFC-113, methyl chloroform, and carbon tetrachloride are the primary controlled substances currently used for solvent cleaning of electronic printed wiring boards, metals, and precision components. Several steps can be taken to conserve and recover these controlled substances while replacement solvents and alternate processes are being developed. Improved operating practices with solvent cleaners, installation of

features to contain solvents, and recycling used solvents can reduce emissions by up to 50 percent (Reference 23).

Further decreases in emissions can be realized by use of carbon adsorption techniques, although the exhaust gas concentration of solvent must be at certain minimum levels entering the adsorber before it becomes practical. Equipment manufacturers are now making accessories for their equipment to help reduce solvent losses. As an example, batch electronic degreasers can be retrofitted for greater freeboard height (the space between the top of the vapor and the top of the tank) and covers to reduce solvent emissions. These modifications are relatively inexpensive and the payback period could be short compared with the increasing costs of controlled solvents.

Although significant reductions in emissions of CAA 1990 controlled cleaning solvents can be, and should be, realized, emphasis should also be placed on finding replacement solvents or alternative cleaning processes that do not use controlled substances, since they will be phased out by 2000 (2002 for methyl chloroform) (Table 4).

### 3. Foam Blowing

CFC recovery and recycling from the foam industry is a difficult challenge. It appears to be technically practical at this time only in open cell foam manufacturing facilities (closed cell foams retain most of the CFCs in the cells unless crushed). Carbon adsorption techniques, although capital intensive, can be used.

The USAF does not manufacture foam products so cannot realize direct recovery and recycling of CFCs in this use category. However, purchasing foams that are blown with CFC replacements would help reduce CFC emissions indirectly.

#### 4. Halon Fire Suppressants

It is estimated that only about 9 percent of all halon consumption is for fighting fires. About 76 percent is banked in systems while the rest (about 15 percent) is controllable emissions (service losses, testing or training, and accidental discharges) (Table 15) (Reference 29). The USAF has eliminated use of halons for training. Recovery and recycling halons can help further reduce emissions from servicing equipment. In addition, recovery and recycling will help preserve scarce halon resources for future mission-critical applications.

Recovery and recycling is appropriate anytime halon has to be removed from an extinguisher or storage container. Halon 1211 extinguishers have traditionally been filled or emptied using pressure transfer of the liquid halon. Losses occur when disconnecting the transfer hoses and allowing the residual halon vapor to escape. Recovery and recycling units eliminate these losses by the use of liquid pumps to transfer the liquid halon then using a compressor to remove all of the vapors and condense them again to a liquid in the storage tank. In addition, the units remove contaminants, such as acids, moisture, oils, and particulates, by passing the halon through replaceable filter-driers. Noncondensable gases can be removed by a purge system, with some small loss of halon vapors.

An ad hoc committee of halon industry representatives worked with Underwriters Laboratories to develop a safety standard for Halon 1211 recovery/recharge equipment. The standard, UL 2006, was released in February 1991 (Reference 53). It requires units to recover and recycle Halon 1211 that has been contaminated with 80 parts per million (ppm) moisture to less than 20 ppm moisture. When purchased, halons are required to have less than 20 ppm moisture, the usual standard, being 6 to 10 ppm. The presence of excess moisture can be the source of other contaminants because moisture causes halon decomposition and formation of acids that can corrode equipment. It is important to remove moisture introduced in halons

during servicing operations or from other sources to less than 20 ppm prior to reuse to prevent such corrosion.

A Halon 1211 recovery and recycling prototype unit was developed under contract to the USAF and demonstrated successfully in 1987 (Reference 54). Based on this work, the Amerex Corporation, a firefighting equipment manufacturer, built and supplied 12 operational prototypes to the U.S. Navy, which were tested at 12 Navy installations. After refinements from the Navy test program, a final design for a Halon 1211 recovery and recycling machine is available for purchase that meets the 99 percent recovery efficiency requirement of UL 2006 (Reference 53). This is the only unit known to be available for Halon 1211 recovery and recycling.

Efficient recovery and recycling of Halon 1301 is more difficult than for Halon 1211 because of the low boiling point (-58 °F) and high vapor pressure (250 lb/in<sup>2</sup> at 25 °C) of Halon 1301. In addition, Halon 1301 is usually super-pressurized with nitrogen to 360 lb/in<sup>2</sup> or 600 lb/in<sup>2</sup>, in extinguishing systems depending on the application. Recovery and recycling equipment must thus be able to handle these higher pressures. Very little work has been done on the effects of the nitrogen pressurizing gas in possibly contaminating the Halon 1301. Other possible contaminants are oil residues, particulates, acids, and moisture.

At least two liquid pumps are commercially available to handle Halon 1301 transfers. Another vapor recovery unit is also commercially available to remove the "vapor heel" from 1301 systems (Reference 51). This vapor recovery unit, however, is not capable of handling the super-pressurization and the nitrogen must be purged, causing some losses of Halon 1301 vapor along with the nitrogen. There are no known recovery and recycling units available on the market for Halon 1301. One company built an in-house unit--not being marketed, which used a "dry cylinder" vapor compressor to prevent oil contamination from the compressor. Most of the 1301 was transferred as a liquid by creating pressure differences using the vapor compressors. Once the liquid was

transferred, the vapor heel was removed using the compressor. This technique eliminated the need for a liquid pump.

There is a definite need for development of a Halon 1301 recovery and recycling unit. It should be able to handle the nitrogen superpressurized containers, remove moisture, acids, particulates, and noncondensable gases from the recovered 1301, with very little loss of 1301 to the atmosphere. However, there has been very little work done on what contaminant levels are acceptable for recycled 1301.

## 5. Other Applications

Some other applications of CFCs and halons are aerosols, sterilants, and specialty products. Replacement agents and alternate processes are available for these applications so that development of use-specific recovery and recycling will not be necessary.

## B. BANK MANAGEMENT

As previously discussed (Section IV, D), the estimates of banked halon (stored in systems or tanks) worldwide vary from 50 to 75 percent (References 29 and 30). With emphasis on recovery and recycling, careful servicing practices, and improved detection systems, the 15 to 40 percent losses attributable to controllable emissions could be reduced to near zero. The remaining emissions of halons estimated at about 9 percent refer to use against actual fires. It is not unreasonable to assume that annual emissions of halons could be in the range of 10 to 15 percent of production. This leaves a considerable amount of halon banked for future use.

Because of the ozone depletion attributable to CFCs and halons, the goal of zero emission should be attained as soon as possible. However, the difficult challenge of finding halon replacement agents or alternate solutions means that adequate reserves of

halons must be maintained to protect USAF mission-critical resources. Even if adequate replacement CFC and halon agents were available, it is impractical in some instances to make system changes, particularly on some weapon systems applications. This circumstance makes it imperative to maintain adequate banks of CFCs and halons for mission-critical applications.

The obvious question is, "what quantities of CFCs and halons are required for how long?" The answers require careful study of each mission-critical application to determine the annual use rate, the need over the projected life of the system, the amounts currently in reserve, and then the amounts required in banks to meet the use rate over the life of the system or application requirement. Of course, the amounts banked could turn from an asset now to a liability later if excessive amounts were left when they were no longer needed and had to be destroyed. Therefore, realistic estimates of USAF bank requirements need to be prepared and reassessed periodically.

## SECTION VI

### CONCLUSIONS AND RECOMMENDATIONS

#### A. CONCLUSIONS

Scientific evidence from studies and measurements indicates that emissions of CFCs and halons worldwide are destroying the stratospheric ozone that screens the earth's surface from excessive ultraviolet radiation. A recent statement by William K. Reilly, Administrator of the U.S. EPA, indicates that recent preliminary scientific information from the National Aeronautics and Space Administration suggests that stratospheric ozone depletion over the last decade has been occurring at a rate faster than previously thought (Reference 55). He further states that the EPA is exploring options including accelerating efforts to bring ozone-safe substitutes on line.

A massive international program is under way to eliminate emissions of ozone-depleting substances according to the Montreal Protocol phaseout schedule. The U.S. is working to a slightly more restrictive phaseout schedule specified by CAA 1990. The DOD and USAF have in turn instituted aggressive programs to reduce emissions of ozone-depleting substances under DOD Directive 6050.9 and AFR 19-15, respectively.

The technologies for replacements or alternatives for CFC applications within the USAF generally appear to be progressing well to meet, or be ahead of, the production phaseout schedules. However, it appears that "drop-in" replacements will not be available, at least in the near term, for any end-use applications. Almost all end-use applications will require new hardware or major alteration of existing hardware for the CFC replacement or alternative. These hardware changes will of course require considerable dollar expenditures to buy the new hardware required or modify the existing hardware. A few CFC uses in the USAF are not practical to change because of the difficulty and cost of converting existing weapon systems hardware. Existing environmental control systems for aircraft and missile guidance control units are some

examples. These mission-critical applications will require use of recovery and recycling equipment to reduce CFC emissions and maintain an adequate bank of appropriate CFCs for the useful life of the systems.

The outlook for near-term halon replacements is not quite as good as for CFC replacement. Although a few potential replacement candidates have been announced, there are trade-offs in either suppression effectiveness, toxicity, or ODPs. Other means of fire protection can be substituted for many of the current uses of halons. Water sprinklers, carbon dioxide, foam, dry chemicals, more fire resistive structures, early detection and alerting, redundancy, and better risk management are a few of the possibilities. There are some halon end-use applications where alternate technologies will not provide sufficient protection and, assuming adequate halon replacements do not emerge, halons will be required for some time. For the USAF, these are mission-critical end uses directly on weapon systems and supporting equipment or facilities. Some examples are fire protection of aircraft electronic equipment spaces and engine nacelles and explosion suppression of aircraft dry bays and fuel tanks. As with CFCs, halon recovery and recycling are essential to reduce emissions and maintain adequate banks of halons to supply mission critical needs throughout the useful life of the systems to be protected.

## B. RECOMMENDATIONS

Many actions and commitments of resources are required at all levels of the USAF to make the successful transition from dependence on CFCs and halons to non-ozone depleting substances in the less than 10 years required by the Montreal Protocol and CAA 1990. The recommendations that follow are somewhat general except for those involving the unique applications of CFCs and halons identified during this study.

1. Policy Guidance
    - a. Institute an aggressive education program on the importance of minimizing emissions of ozone-depleting substances.
    - b. Promote a thorough preventive maintenance program on all equipment involving ozone-depleting substances to minimize leaks and accidental releases.
    - c. Identify resources and schedules required to convert to nonozone-depleting substances and input into the budget and planning process as soon as possible.
  2. Refrigerants
    - a. Ensure that refrigerants are recovered from all refrigeration and air-conditioning systems prior to service or disposal.
    - b. Procure refrigeration and air-conditioning systems that use nonozone-depleting refrigerants as soon as they are commercially available.
  3. Cleaning Solvents
    - a. Modify existing cleaning solvent systems to minimize CFC emissions while making the transition to nonozone-depleting solvents.
    - b. Qualify and convert to cleaning solvents that are nonozone-depleting as soon as possible; eliminate uses of CFCs, methyl chloroform, and carbon tetrachloride.
  4. Foams
    - a. Procure foams that are blown only with nonozone-depleting substances as soon as they are commercially available to reduce CFC emissions and encourage industry to convert.
  5. Halons
    - a. Continue research program to identify halon replacements for mission-critical applications.
    - b. Expand program to encourage nonhalon fire protection strategies in all areas similar to Engineering Technical Letter 89-3 for Electronic Equipment.

6. Mission-Critical Applications
  - a. Establish a list of justified and accepted mission-critical applications of CFCs and halons.
  - b. Expand AFR 19-15 reporting requirements to include accurate projection of mission-critical needs of CFC and halons throughout the useful life of the systems.
  - c. Evaluate new aircraft environmental control systems designs for use of CFC replacement refrigerants or use of air cycle refrigeration.
7. Miscellaneous
  - a. Survey use of CFCs as sterilants in hospitals and other medical facilities and determine requirements for conversion to replacements or alternate processes.
  - b. Determine exact requirements for Halon 2402 in present and future missile thrust vector control systems and establish a program to find a replacement.
  - c. Establish requirements for Halon 1202 throughout the expected life of affected aircraft and ensure adequate supplies will be available.
8. Recovery/Recycling/Reclamation and Bank Management
  - a. Establish an USAF-wide aggressive recovery and recycling or reclamation program to meet the spirit of CAA 1990 to reduce emissions of CFCs and halons and to conserve critical resources for present and future needs.
  - b. Establish research program to determine the purity requirements for recovered and recycled halons prior to reuse in systems.
  - c. Establish government program to develop Halon 1301 recovery and recycling equipment since industry does not have one available.
  - d. Establish USAF-wide bank management program to identify which CFCs and halons need to be banked and project the amounts required to meet future mission-critical applications.

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